Lung function, respiratory symptoms, and occupational exposure

A five-year prospective study among employees in Norwegian smelters

A thesis by

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1. SUMMARY

This thesis examines the association between respiratory symptoms, lung function, annual decline in lung function, and occupational exposure in Norwegian smelters using both a qualitative and a quantitative exposure classification.

Aims

The aims of the thesis were: i) to generate a qualitative exposure classification; ii) to investigate the associations between job category and the prevalence of respiratory symptoms, and job category and lung function at the time of inclusion to the study using the qualitative exposure classification; iii) to generate a job exposure matrix (JEM) for dust exposure; iv) to investigate the association between annual decline in lung function, expressed by forced expiratory volume in one second (FEV_1), and job exposure using both the qualitative and quantitative exposure classifications.

Material and Methods

All employees (N=3924), aged 20 to 55 years at inclusion, were examined annually over five years (16 570 health examinations). At each health examination, spirometry was performed and a respiratory questionnaire completed, including questions on respiratory symptoms, familial asthma, allergy, doctor-diagnosed asthma, smoking habits, previous exposure, and job title. Employees were classified according to their current job function: i) line operators were employed full time on the production line, ii) non-exposed employees did not work in production, and iii) remaining employees were classified as non-line operators. The 24 smelters and related workplaces were grouped as follows by similarities in production technology: i) ferrosilicon alloys (FeSi) and silicon metal (Si-metal), ii) silicon manganese (SiMn), ferromanganese (FeMn), and ferrochromium (FeCr), iii) silicon carbide (SiC), and iv) other. The arithmetic mean (AM) and geometric mean (GM) of 2619 personal dust exposure measurements, taken between 1996 and 2004, were applied in constructing a JEM for the FeSi/Si-metal and SiMn/FeMn/FeCr production groups. The associations between job category and the prevalence of respiratory symptoms as well as lung function at inclusion to the study were investigated using multivariate logistic regression and multivariate linear regression, respectively. The association between lung function expressed as FEV_1 per squared height (FEV_1/height^2)

and occupational exposure, using both the qualitative exposure classification and the quantitative JEM, was investigated using multivariate linear mixed model analyses.

Results

The mean age of the participants at inclusion was 38.6 years (standard deviation 9.2 years); 88.5% were male. The odds ratios (OR) for dyspnea, cough without a cold, and phlegm in employees reporting previous exposure to dust, fumes, or gases compared with employees reporting no such exposure were 1.4 (95% confidence intervals (CI): 1.1–1.7), 1.4 (1.2–1.8), and 1.3 (1.0–1.7), respectively. The OR for respiratory symptoms was higher in relation to previous exposure than current job function except for phlegm. The adjusted FEV_1 at inclusion was 87 ml (95% CI: 33–141) and 65 ml (12–118) lower in line and non-line operators, respectively, compared with non-exposed employees. The prevalence of airflow limitation (FEV_1/forced vital capacity (FVC) below the 5^{th} percentile of the predicted value) was 4.7% in non-exposed employees, 7.5% in non-line operators, and 8.3% in line operators.

In the longitudinal analyses using the qualitative exposure classification, we found that the difference in annual change of $FEV_1/height^2$ between line operators and non-exposed employees was –2.3 (95% CI: –4.3 to –0.3) $(ml/m^2)\times year^{-1}$ and –5.6 (–10.4 to –0.7) $(ml/m^2) \times year^{-1}$ in the FeSi/Si-metal and SiC production groups, respectively.

In the FeSi/Si-metal production group, the median GM of dust exposure was 2.3 mg/m^3 (10-90% percentiles: 0.03–5.6) compared with 1.6 mg/m^3 (0.02–2.3) in the SiMn/FeMn/FeCr production group. Multivariate analyses showed that the dust exposure concentration level of the employees decreased significantly with increasing age (FeSi/Si-metal), was significantly lower in females than in males, and was significantly higher in current smokers than in those who had never smoked.

In the longitudinal analyses using the quantitative JEM for exposure classification, we found that the annual decline of $FEV_1/height^2$ (δFEV_1) regarding dust exposure was –0.49 (95% CI: –0.94 to –0.039) $(ml/m^2)\times(mg/m^3)^{-1}\times year^{-1}$. In the FeSi/Si-metal and SiMn/FeMn/FeCr smelters, δFEV_1 was –0.42 (–0.95 to 0.11) and –1.1 (–2.1 to –0.12) $(ml/m^2)\times(mg/m^3)^{-1}\times year^{-1}$, respectively. In current smokers, δFEV_1 was –1.6 (–3.1 to

–0.15) $(ml/m^2)\times(mg/m^3)^{-1}\times year^{-1}$ compared with non-smokers. Among non-smokers δFEV_1 was –0.86 (–1.6 to -0.10) and –1.1 (–2.5 to 0.25) $(ml/m^2)\times(mg/m^3)^{-1}\times year^{-1}$ in the FeSi/Si-metal and SiMn/FeMn/FeCr smelters, respectively.

Conclusions

In Norwegian smelters both the prevalence of respiratory symptoms and the level of lung function were found to be associated with the current job function of employees. Furthermore, an increased decline in lung function of employees was demonstrated using both the qualitative exposure classification (significant for FeSi/Si-metal and SiC production) and the quantitative JEM (FeSi/Si-metal and SiMn/FeMn/FeCr). The latter association was significant for workers in SiMn/FeMn/FeCr smelters, but was significant only among non-smokers in FeSi/Si-metal smelters.

2. LIST OF PUBLICATIONS

Paper I

Laier Johnsen H, Søyseth V, Hetland SM, Šaltytė Benth J, Kongerud J. Production of silicon alloys is associated with respiratory symptoms among employees in Norwegian smelters. Int Arch Occup Environ Health 2008;81:451-459.

Paper II

Johnsen HL, Kongerud J, Hetland SM, Benth JS, Soyseth V. Decreased lung function among employees at Norwegian smelters. Am J Ind Med 2008;51(4):296-306.

Paper III

Søyseth V, Laier Johnsen H, Šaltytė Benth J, Hetland SM, Kongerud J. Production of silicon metal and alloys is associated with accelerated decline in lung function. J Occup Environ Med. 2007;49(9):1020-1026.

Paper IV

H Laier Johnsen, SM Hetland, J Šaltytė Benth, J Kongerud, V Søyseth. Quantitative and qualitative assessment of exposure among employees in Norwegian smelters. Ann Occup Hyg 2008;52(7):623-633

Paper V

H Laier Johnsen, SM Hetland, J Šaltytė Benth, J Kongerud, V Søyseth. Dust exposure estimated by a job exposure matrix is associated with increased annual decline of FEV_1. *A 5-year prospective study among employees in the Norwegian smelting industry.* Submitted 2008.

3. WORDS AND ABBREVATIONS

The following abbreviations are used in the thesis:

ATS	American Thoracic Society
CaC_2	Calcium carbide
CI	Confidence interval
CO	Carbon monoxide
COPD	Chronic obstructive pulmonary disease
CSP	Crushing, screening, and packing
ECSC	European Community for Steal and Coal
ERS	European Respiratory Society
FeCr	Ferrochromium
FeMn	Ferromanganese
FeSi	Ferrosilicon
FEV_1	Forced expiratory volume in one second
FVC	Forced vital capacity
LLN	Lower limit of normal
LLN FEV_1/FVC	FEV_1/FVC below the 5^{th} percentile of the predicted value
NIOH	National Institute of Occupational Health
NO_x	Nitrogen oxides
OR	Odds ratio
PAH	Polycyclic aromatic hydrocarbons
SiC	Silicon carbide
SiMn	Silicon manganese
Si-metal	Silicon metal
SO_2	Sulfur dioxide
TGSF	Thermally generated silica fume
TiO_2	Titanium(II)oxide

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5. BACKGROUND

Employees in the smelting industry are exposed to dust, fumes, and gases of various compositions that may be harmful to the respiratory tract. The association between this occupational exposure and lung function has been investigated in several cross-sectional studies. In some of these, occupational exposure was found to be associated with impairment of lung function (Taddei et al. 1979; Langard 1980; Peters et al. 1984; Osterman et al. 1989b; Marcer et al. 1992). Other studies have not confirmed these findings (Johansen and Vale 1982; Cherniack and Boiano 1983; Petran et al. 2000). Mortality studies have indicated an increased mortality from non-malignant lung diseases in some productions (Hobbesland et al. 1997; Romundstad et al. 2002).

In an extensive literature review published in 1998 by the International Agency for the promotion of silicon metal (AIS), the association between thermally generated silica fume, TGSF (amorphous silica fume), and respiratory diseases was investigated (Galton-Fenzi 1998). It was concluded that there was evidence that TGSF is associated with respiratory disease. Several studies suggesting that silicosis occurs showed that crystalline rather than amorphous silica exposure was the most likely cause. A majority of the most recent studies in the review indicated an association between increased prevalence of respiratory symptoms and exposure to TGSF. Regarding lung function, various pictures including obstructive, restrictive, and mixed ventilatory changes were found. Galton-Fenzi concluded that there was an urgent need for longitudinal studies in the smelting industry using a quantitative exposure classification to determine if any association between exposure to TGSF and respiratory tract disease existed (Galton-Fenzi 1998).

Under Norwegian Legislation, workers exposed to potentially harmful agents must be monitored, and where proper health examination methods exist these should be used in the surveillance. As part of this surveillance, and in the light of the above mentioned findings, the Norwegian smelting industry in 1996 initiated a longitudinal study. The aims of that study were: i) to coordinate and quality assure the survey of lung diseases in the smelters, and ii) to explore the association between current occupational exposure in the smelters and development of chronic obstructive lung disease.

5.1. COPD

Chronic obstructive pulmonary disease (COPD) is defined by the Global Strategy for the Diagnosis, Management, and Prevention of COPD (GOLD) as follows: COPD is a preventable and treatable disease with some significant extrapulmonary effects that may contribute to the severity in individual patients. Its pulmonary component is characterized by airflow limitation that is not fully reversible. The airflow limitation is usually progressive and associated with an abnormal inflammatory response of the lung to noxious particles or gasses (Rabe et al. 2007).

In COPD, the main site of airflow limitation is the smaller conducting airways (less than 2 mm in diameter) (Hogg 2004; Vestbo and Hogg 2006). The processes contributing to obstruction in the small conducting airways include disruption of the epithelial barrier, infiltration by inflammatory cells, predominantly neutrophils and lymphocytes, and deposition of connective tissue in the airway walls. This, together with impairment of the mucociliary clearance apparatus, results in accumulation of inflammatory mucus exudates in the lumen of the small airways (Hogg et al. 2004). Many patients also show destruction of the respiratory bronchioles, leading to emphysema (Hogg 2004; Girod and King 2005).

Classification of COPD according to the GOLD criteria (Rabe et al. 2007):
Spirometric classification of COPD severity based on post-bronchodilator FEV_1

Stage	Characteristics: Spirometry
I: Mild COPD	$FEV_1/FVC < 0.70$ $FEV_1 \geq 80\%$ predicted
II: Moderate COPD	$FEV_1/FVC < 0.70$ $50\% \leq FEV_1 < 80\%$ predicted
III: Severe COPD	$FEV_1/FVC < 0.70$ $30\% \leq FEV_1 < 50\%$ predicted
IV: Very severe COPD	$FEV_1/FVC < 0.70$ $FEV_1 < 30\%$ predicted or $FEV_1 < 50\%$ predicted plus chronic respiratory failure[1]

[1] Respiratory failure: arterial partial pressure of oxygen (Pa_{O2}) < 8.0 kPa (60 mmHg) with or without Pa_{CO2} > 6.7 kPa (50 mmHg) while breathing air at sea level.

Smoking is the major cause of COPD worldwide, but noxious particles or gasses in the workplace atmosphere may also contribute to the development of COPD (Becklake 1989; Bakke et al. 1991b; Hendrick 1996; Hnizdo et al. 2002; Viegi and Di 2002; Hnizdo and Vallyathan 2003; Trupin et al. 2003; Toren and Balmes 2007; Blanc and Toren 2007). The American Thoracic Society (ATS) states that as many as 10 to 20 % of asthma and COPD cases are related to workplace exposure (Balmes et al. 2003). As such, for the prevention of COPD, better quantification of the risk factors involved in the development of COPD is vital (Balmes et al. 2003).

Even though the specific etiologic role of the more than 400 constituents of tobacco smoke is not known, there is a consensus that cigarette smoking is a specific cause of COPD (Balmes et al. 2003). Longitudinal epidemiologic studies have demonstrated a dose-response relationship between the amount smoked and an observed accelerated annual decline in lung function (Fletcher and Peto 1977; Anthonisen et al. 1994). As cigarette smoke is a mixture of particulates and gases, it can be compared to a mixed inhalation exposure at a workplace (Becklake 1989). We therefore hypothesized that a dose-response relationship might exist between workplace exposure in the Norwegian smelting industry and an increased annual decline in lung function.

Expiratory airflow limitation, best measured by spirometry, is the hallmark of COPD (Rabe et al. 2007). According to the GOLD criteria, the presence of a postbronchodilator $FEV_1/FVC < 0.70$ confirms the presence of airflow limitation that is not fully reversible (Rabe et al. 2007). Mucus hypersecretion and ciliary dysfunction, leading to chronic cough and sputum production, can be present many years before other symptoms or physiologic abnormalities develop (Pauwels et al. 2001; Rabe et al. 2007). Thus, the survey of employees in the present study included not only spirometry and reversibility test but also a respiratory questionnaire.

5.2. Occupational exposure and COPD

The classic mineral dust-induced pneumoniconiosis has decreased in frequency because of better control of exposure in most countries (Meyer et al. 2001; Hnizdo and Vallyathan 2003). Instead, obstructive airway diseases (asthma, COPD, and emphysema) have emerged as one of the most prevalent categories of occupational respiratory disorders (Meyer et al. 2001). However, as COPD is a multifactor disease which is strongly associated with non-occupational exposures, it is a challenge to investigate its relationship to work exposure. Longitudinal population studies of the association between lung function and occupational exposure have, nevertheless, reported an association between occupational exposure and increased annual decline in lung function (Kauffmann et al. 1982; Humerfelt et al. 1993). In industry-specific studies, a significant relationship between exposure and accelerated decline in lung function has been found among coal miners, aluminum potroom workers, coke oven workers, and tunnel construction workers (Cowie and Mabena 1991; Soyseth et al. 1997; Ulvestad et al. 2001; Wu et al. 2004; Bakke et al. 2004).

5.3. Previous studies of obstructive lung disease

It has been known for years that employees in the smelting industry are exposed to dust, fumes, and gases of various compositions and in varying concentrations.

5.3.1. Studies of lung function

The association between the occupational exposure in smelters and lung function (expressed by FEV_1) has been investigated in several cross-sectional studies (Taddei et al. 1979; Langard 1980; Johansen and Vale 1982; Cherniack and Boiano 1983; Peters et al. 1984; Osterman et al. 1989b; Marcer et al. 1992)**.** In some of these, occupational exposure in the smelting industry was found to be associated with impairment of lung function (Taddei et al. 1979; Langard 1980; Peters et al. 1984; Osterman et al. 1989b; Marcer et al. 1992). Other studies did not confirm these findings (Johansen and Vale 1982; Cherniack and Boiano 1983; Petran et al. 2000). For FeMn and SiMn production, there are only a few peer-reviewed studies analyzing the relationship between occupational exposure and lung function. However, one study from a large manganese mine revealed lower lung function in exposed workers compared to non-exposed controls (Boojar and Goodarzi 2002).

5.3.2. Studies of respiratory symptoms

Regarding respiratory symptoms, in some of the cross-sectional studies, an increased prevalence of symptoms such as "bronchitis symptoms," dyspnea, wheeze, cough, and phlegm has been reported in workers in the smelting industry compared with the general population or an internal control group (Taddei et al. 1979; Langard 1980; Petran et al. 2000). In other studies no significant differences were found between the prevalence of respiratory symptoms in exposed employees and the control groups (Johansen and Vale 1982; Cherniack and Boiano 1983; Osterman et al. 1989a).

5.3.3. Mortality studies

Mortality studies have indicated an increased mortality of bronchitis, emphysema, and asthma among furnace workers in the FeSi/Si-metal industry, though not in the FeMn/SiMn/FeCr industry (Hobbesland et al. 1997). Further, a positive association between furnace work and mortality from non-malignant respiratory diseases has been found in SiC production (Romundstad et al. 2002). Increased mortality from COPD and cor pulmonale was found in an FeSi, Si-metal, and SiC producing smelter in West Virginia (Cherniack and Boiano 1983).

5.3.4. Population studies

In a Norwegian population study, Humerfelt et al. found that in men aged 30-46 years with occupational quartz exposure and normal chest radiographs, the duration of occupational quartz exposure was an independent determinant of spirometric airflow limitation (Humerfelt et al. 1998a).

6. AIMS OF THE STUDY

The overall goal of this longitudinal epidemiologic study of lung function and respiratory symptoms among employees at Norwegian smelters was to investigate the association between current occupational exposure in the smelters and the risk of developing chronic obstructive lung disease. To achieve this overall goal the following aims were established:

- To create a qualitative exposure classification of the various occupations in Norwegian smelters, and to investigate the relationship between this job classification and the prevalence of respiratory symptoms as well as the level of lung function among employees at inclusion to the study.

- To generate a quantitative job exposure matrix (JEM) for dust exposure in Norwegian smelters and assign this JEM to the study population.

- To investigate the association between annual change in lung function, expressed by FEV_1, and current job exposure using both the qualitative and quantitative JEM for exposure classification.

- To calculate the prevalence of a positive reversibility test in participants with airway obstruction.

- To investigate the association between previous occupational exposure and the risk of developing COPD.

- To investigate whether the risk of developing COPD is higher in subjects with allergy than in those without allergy.

7. THE NORWEGIAN SMELTING INDUSTRY

Norway is one of the world's largest producers of metallurgical grade silicon and is also one of the leading countries in the development and supply of electric arc furnaces used in the smelting processes.

Norwegian smelters are mainly sited along the coastline, primarily because of access to hydroelectric energy and transportation (by sea). The location of the smelters has been, and remains, of great importance for employment and sustainability of the often small coastal communities.

The smelting processes require large amounts of energy. Elkem Salten, one of the newest and largest plants in the Western world, consumes approximately 1 TWh of energy per year. This is equivalent to the annual energy consumption of 50 000 households, i.e., approximately half of all households in Bergen.

7.1. Production

Norwegian smelters produce ferrosilicon alloys (FeSi), silicon metal (Si-metal), alloys of ferromanganese (FeMn), silicomanganese (SiMn) and ferrochromium (FeCr), silicon carbide (SiC), titanium(II)oxide (TiO_2) together with pig iron, and calcium carbide (CaC_2). All the production processes require high temperatures (1500˚ to 2700˚C), thus the high energy consumption. Raw materials are transported into the plant and fed into a smelting furnace. The production processes require a solid form of carbon (such as coke, coal, and in some cases charcoal and wood chips) to reduce the minerals to molten metals, plus a direct supply of electrical energy to achieve the necessary high process temperature. The supply of electrical power depends on the production process. In electric arc furnaces electrical power (alternating current) is supplied through three submerged carbon electrodes, either Søderberg electrodes, prebaked electrodes, or electrodes combining the characteristics of the two. Søderberg electrodes are self-baking carbon electrodes covered with an iron or steel casing, while prebaked electrodes are baked before they are used in the smelting process. In SiC production an Acheson furnace is used (see below).

In the FeSi, Si-metal, FeMn, SiMn, FeCr, TiO_2, and CaC_2 production, when tapped from the furnaces, the molten metals or ferroalloys are poured out to cool in molds and then crushed to specified sizes. In other production processes, some end products are sized by granulation, i.e., the molten alloys are poured out in certain ways to produce droplets, which are rapidly cooled to produce solid granules.

Dust is emitted into the working atmosphere during raw material handling, smelting, tapping (condensation of tapping fumes), crushing, and handling of the end products.

Job tasks by job title and department in the smelters are described in table 1. For SiC producing smelters, a job classification used in an earlier study by Romundstad was used (Romundstad et al. 2002; Foreland et al. 2008).

The smelters and related workplaces serving the smelters were divided into four production groups according to similarities and differences in production technology. These groups were: i) ferrosilicon alloys (FeSi) and silicon metal (Si-metal); ii) other ferroalloys such as silicomanganese (SiMn), ferromanganese (FeMn), and ferrochromium (FeCr); iii) silicon carbide production; and iv) other production.

Photo: Eramet Norway AS Sauda

Table 1 Job titles and job tasks by department at Norwegian smelters[1].

Department	Job title	Job tasks
Logistic	Transport operator	Unloading, loading, crane-, lorry- and truck driving.
	Raw material worker	Handling and mixing of the raw materials before charging the furnaces. Cleaning of conveyor belt.
	Logistic worker [b]	Unloading, loading, crane-, lorry- and truck driving. Handling and mixing of the raw materials before charging the furnaces. Cleaning of conveyor belt.
Furnace house	Furnace operator	Controlling process from control room. Stoking car. Cleaning of area.
	Tapper	Tapping of ferroalloys and silicon metals from furnaces. Maintenance of tapping launders. Cleaning of area.
	Other job functions [c]	Granulating, refining, casting, pelletising, producing of special alloys and cleaning of area.
	Furnace department worker	Job functions carried out in the furnace house not coded as one of the job titles above (see methods).
Filter	Filter department worker	Dust collection, granulating, filling of big bags. Cleaning of area.
Electrode	Electrode department worker	Electrode assembly, welding of electrode casing, filling of electrode paste.
Refractory	Ladle refractory workers [d]	Maintenance and repair of ladles and tapping launders.
Laboratory	Laboratory department worker	Sampling of metal product. Analytic work in the laboratory.
CSP[a]	CSP department worker [e]	Crushing, screening and packing of the final metal and alloy products. Cleaning of area.
Maintenance	Mechanic [f]	Maintenance of machinery and production equipment.
	Electrician	Maintenance of electrical installations.
	Cleaner	Cleaning of the administration buildings and offices, control rooms and wardrobes in the production buildings.
	Other job functions	Wet filtering and handling of hazardous waste as well as mechanics and electricians not coded separately (one smelter).
Sinter plants	Sintering worker	Sintering fine grain raw material ores into coarser materials (Mn, Cr, Fe).
Administration	Office work only	Never exposed in the production.
	Partly exposed	Primarily office work, but some periodically exposure in the production process.

[1] FeSi/Si-metal smelters, SiMn/FeMn/FeCr smelters and Other production.
[a] Crushing, screening and packing (CSP).
[b] CSP department workers were included in this job title in three smelters.
[c] In one smelter electrode workers and refractory workers were included in the furnace house.
[d] Electrode workers were included in three smelters.
[e] Filter department workers were included in one smelter.
[f] Electrode workers were included in three smelters. Refractory workers were included in one smelter.

7.1.1. FeSi alloys and Si-metal production

In the FeSi/Si-metal production group, the reduction materials are mixed with quartz and iron sources or other compounds depending on the end products. The raw materials are then charged into the top of the cylindrical furnaces (figure 1), which have a diameter of 5 to 13 meters. The smelting temperature at the center of the furnaces is typically between 1500 and 2000 ˚C. The furnaces are partly open (Zulehner 1993; Neuer and Rau 1993).

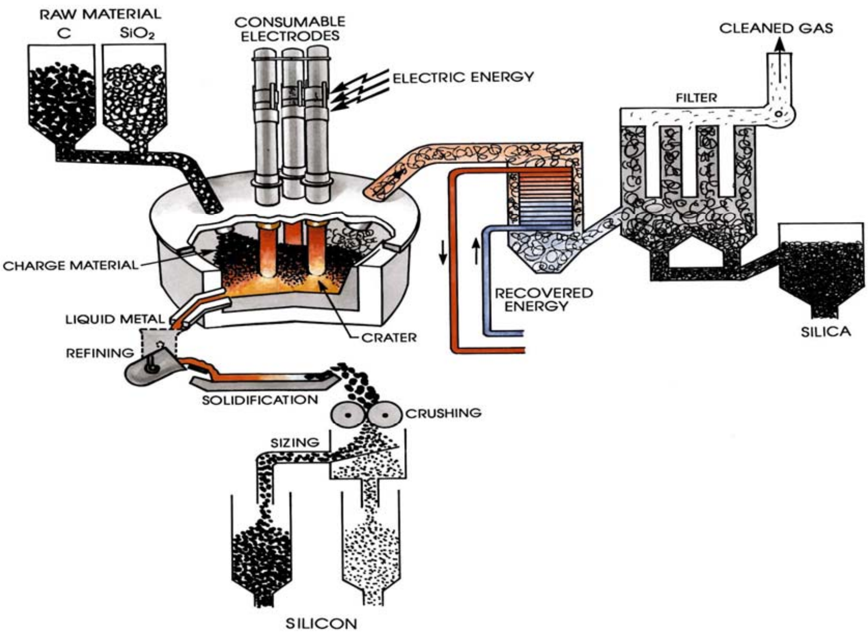


Figure 1. Electric arc furnace, FeSi and Si-metal production.
Illustration: A. Schei, J.Kr. Tuset, and H. Tveit, High Silicon Alloys, 1998

7.1.2. SiMn, FeMn, and FeCr alloy production

Depending on the required end product in the SiMn/FeMn/FeCr production group, the reduction materials are mixed with manganese or chromium ore, iron sources, or other compounds such as quartz (Wellbeloved et al. 1990; Fichte 1986). In the sinter plants of FeMn and FeCr production, fine grain raw material ores are sintered into coarser materials. The temperature at the center of the furnace is as high as to 1600 ˚C. In contrast to FeSi and Si-metal production, where furnaces are semi-closed or open air furnaces, the furnaces in FeMn, SiMn, and FeCr alloy production are closed.

In Norway closed furnaces have wet scrubbers, scrubbing the furnace gas (with water) to catch the particulates. Semi-closed or open air furnaces use “dry filter bag technology abatement” to trap the condensed particles from the furnace gas. Thus, there may be differences in the overall dust and gas exposure levels of the furnace house operators in the various production groups.

7.1.3. SiC production

The furnaces in SiC production differ from those of the other production groups, as SiC is produced in Acheson furnaces (Liethschmidt 1993). Acheson furnaces are rebuilt and demolished for every smelting and the end products of the smelting process are cooled in the furnaces and thereafter further treated to achieve the specified quality and size (figure 2). The smelting temperature in SiC production is even higher than in the other types of production (up to 2700 ˚C in the center of the furnace), but the emissions from the smelting process are comparable.

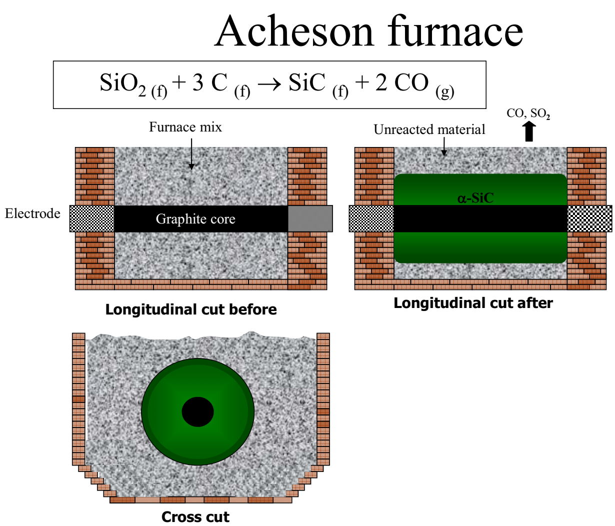


Figure 2. Acheson furnace.
Illustration: Solveig Føreland NIOH

Acheson furnace
Photo: Washington Mills AS Norway

7.1.4. Other production

The “other production” group included various facilities: one smelter producing titanium(II)oxide (TiO_2) and pig iron (Woditsch and Westerhaus 1992); one electrode paste production plant also calcinating anthracite (European Commission 2001); one facility producing Ceramite, a product made from inorganic dust; one company providing smelter maintenance; and one ferroalloy research and development facility.

7.1.5. Participating smelters and related workplaces

The names of the participating facilities listed in table 2 are those of the smelters and related workplaces at inclusion to the study in 1997, as some of the facilities changed name during the study period. A number of other closed down: Elkem Meraker, Elkem Fiskaa Silicon, Fesil Lilleby Metal, Globe Norge Hafslund, and Odda Smelteverk. Today (2008) a total of 2 340 people are employed in the Norwegian smelting industry (Source: the Federation of Norwegian Industries).

Table 2 Participating smelters and related workplaces[1].

Production group Smelter	Surveillance period[2]	Participants 20-55 years $N_{20\text{-}55}$ (N_{all})	Females 20-55 years N (%)	Health Examinations $N_{20\text{-}55}$ (N_{all})	Follow-up $Time_{20\text{-}55}$ years
FeSi/Si-metal: total		1687 (1924)	200 (11.9)	7105 (7902)	5654.2
Elkem bjølvefossen AS	31.03.1997–19.12.2002	245 (285)	54 (22.0)	1179 (1336)	905.2
Elkem Bremanger	21.10.1997–21.03.2003	279 (344)	53 (19.0)	1175 (1369)	989.3
Elkem Meraker[3]	13.10.1997–12.04.2002	102 (123)	6 (5.9)	393 (477)	312.1
Elkem Salten	15.10.1997–18.12.2002	185 (215)	13 (7.0)	1020 (1135)	834.8
Elkem Thamshavn	01.06.1997–18.12.2002	154 (175)	19 (12.3)	711 (779)	579.4
Elkem Fiskaa Silicon[3]	16.10.1997–01.09.2003	135 (156)	13 (9.6)	599 (669)	483.5
Fesil ASA Holla Metall	12.01.1997–18.12.2001	169 (174)	12 (7.1)	744 (768)	591.7
Fesil ASA Lilleby Metall[3]	03.11.1997–29.10.2002	88 (94)	7 (8.0)	210 (221)	189.4
Fesil ASA Rana Metall	27.10.1997–17.12.2002	104 (122)	7 (6.7)	490 (544)	410.2
Finnfjord Smelteverk	11.12.1997–12.05.2003	127 (131)	10 (7.9)	412 (422)	294.0
Globe Norge AS Hafslund Metall[3]	08.10.1998–02.02.2000	99 (105)	6 (6.1)	172 (182)	64.5
SiMn/FeMn/FeCr: total		933 (1107)	103 (11.0)	4230 (4779)	3400.9
Eramet Norway PEA Porsgrunn	28.10.1997–05.02.2003	246 (280)	22 (8.9)	1155 (1258)	936.1
Eramet Norway Sauda	06.10.1997–12.02.2003	337 (417)	46 (13.6)	1523 (1740)	1202.0
Tinfoss Jernverk AS Øye Smelteverk	26.02.1998–30.03.2002	199 (231)	23 (11.6)	802 (919)	636.1
Elkem Rana (Rio Doce Manganese)	30.07.1997–17.12.2002	151 (179)	12 (7.9)	750 (862)	581.1
SiC: total		464 (489)	35 (7.5)	1663 (1714)	1301.1
Orkla Exolon AS (Washington Mills)	07.10.1997–16.01.2003	114 (127)	7 (6.1)	489 (520)	405.5
St. Goubain Ceramic AS Arendal	25.01.1999–29.01.2003	186 (186)	11 (5.9)	539 (539)	378.2
St. Goubain Ceramic AS Lillesand	12.02.1997–12.12.2003	164 (176)	17 (10.4)	635 (655)	517.5
Other: total		840 (966)	114 (13.6)	3572 (4039)	2784.3
Elkem Fiskaa Carbon	16.10.1997–10.04.2003	128 (140)	13 (10.2)	600 (633)	493.5
Fiskaa Industriservice	04.03.1997–03.12.2003	57 (73)	1 (1.8)	275 (326)	233.2
Elkem Materials	05.01.1997–07.04.2003	83 (90)	27 (32.5)	360 (397)	302.8
Elkem Research	01.04.1997–09.04.2003	95 (115)	15 (15.8)	398 (471)	327.4
Odda Smelteverk[3]	11.09.1997–27.11.2001	265 (303)	34 (12.8)	1075 (1224)	795.9
Tinfoss Titan & Iron	01.11.1997–08.11.2001	212 (245)	24 (11.3)	864 (988)	631.6
All: total	05.01.1997-18.12.2003	3924 (4486)	452 (11.5)	16570 (18434)	13140.5

[1] Names of 1997 with the present name in parentheses.
[2] Dates in the format: DD.MM.Year
[3] Smelters closed down during the study period.

7.2. Exposure

The employees, and in particular those in the furnace house, are exposed to different air pollutants. These air pollutants include inorganic dust, organics such as polycyclic aromatic hydrocarbons (PAH), and gases such as nitrogen oxides (NO_x), sulfur dioxide (SO_2), and carbon monoxide (CO). The concentration of these pollutants differs between smelters as well as within different areas of each smelter.

With the exception of three smelters, personal "total dust" measurements were available in all smelters and related workplaces over the study period. In two of the three exceptions, no measurement data existed and in one smelter only measurements by cyclone (respirable dust) were available. Measurements of PAH, NO_x and CO were available in limited numbers and in only a few of the smelters. We therefore decided to use "total dust" for the JEM.

7.2.1. Particle size and fraction

Paticulate size can be classified in different ways. In occupational medicine, it is common to use the following CEN 1993 definition (CEN convention: NS-EN 481 1993):

- Inhalable fraction: The mass fraction of total airborne particles inhaled through the nose and mouth. The inhalable convention includes 97% of airborne particles with an aerodynamic diameter D=1µm, 77% of airborne particles with D=10µm, and 50% of airborne particles with D=100µm.
- Thoracic fraction: The mass fraction of inhaled particles penetrating beyond the larynx. The thoracic convention includes 97% of airborne particles with D=1µm, 50% of airborne particles with D=10µm, and 0.6% of airborne particles with D=30µm.
- Respirable fraction: The mass fraction of inhaled particles penetrating to the unciliated airways. The respirable convention includes 97% of airborne particles with D=1µm, 50% of airborne particles with D=4µm, 1.3% of airborne particles with D=10µm, and 0.1% of airborne particles with D=15µm.

By convention means the relationships between the aerodynamic diameter and the fractions to be collected or measured, which approximate for the fractions penetrating to regions of the respiratory tract under average conditions.

Particle aerodynamic diameter (*D*): The diameter of a sphere of density 1 g×cm^{-3} with the same terminal velocity due to gravitational force in calm air as the particle, under the prevailing conditions of temperature, pressure, and relative humidity.

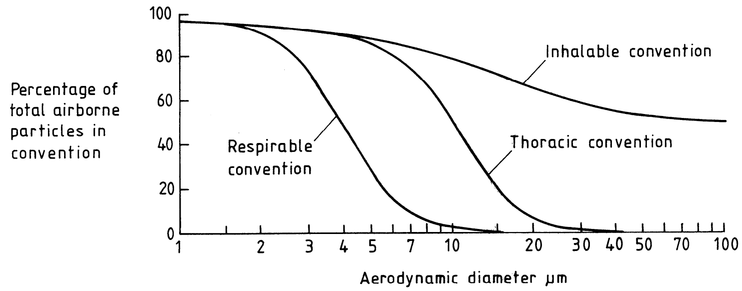


Figure 1. The inhalable, thoracic and respirable conventions as percentages of total airborne particles

Figure 3 of NS-EN 481:1993, reprinted by Helle Laier Johnsen in this thesis with permission from Pronorm AS 1/2008. Reprint without permission is not allowed.

The health hazard of a pollutant depends on its chemical nature and on the site of its deposition in the airways (Muir and Verma 1993). As the regional deposition of particles in the lung is mainly a function of particle size, it is important to measure particles of a size relevant to the site of pathogeneses in the lungs. The airflow characteristic of COPD is associated with lesions that obstruct the small conducting airways of the lung and may produce emphysematous destruction of the lung's elastic recoil force (Jeffery 2001; Hogg 2004; Girod and King 2005). However, the cough and sputum production in chronic bronchitis is due to inflammation in the epithelium of the central airways larger than 4 mm in internal diameter (Hogg 2004). Therefore, the measurement of "total dust," resembling the thoracic convention, may be the most appropriate approach when investigating both respiratory symptoms and lung function.

7.2.2. Previous studies of dust exposure in the smelting industry

Total dust exposure in the Norwegian smelting industry has been described to some extent in previous studies (Langard 1980; Kjuus et al. 1986; Hobbesland et al. 1997).

Historically, dust concentrations over 5 mg/m^3 and up to 30 mg/m^3 were not uncommon (Langard 1980; Kjuus et al. 1986). In a study from 1997, Hobbesland et al. reported that furnace workers in FeSi and Si-metal production had a total dust exposure of 3.4 mg/m^3 (95% confidence interval: 1.1-13.8) in the period 1986 to 1990 (Hobbesland et al. 1997). This is comparable to our findings in the present study, indicating that there were no changes in workplace exposure from 1990 to 1996. In a study of adverse health effects associated with production of ferrosilicon and calcium silicon alloys as well as silicon metal in a smelter in West Virginia, respirable personal dust measurement were performed (Cherniack and Boiano 1983). In that study the highest exposure levels were found in ladle lining and in the mixhouse. In a Norwegian study, Føreland et al. found that in SiC-producing smelters exposure levels were generally below the current Norwegian occupational exposure limit, but that high exposure to fibers and respirable dust still occured in the furnace department (Foreland et al. 2008).

The size of the particulates in the workplace atmospheres in the smelters varies from particulates with a primary diameter < 0.01 µm to larger agglomerates of particulates (Kolderup 1977; Ellingsen et al. 2003; Friede 2006; Skogstad et al. 2006). Few studies have focused on the important issue of particle size distribution in the workplace atmosphere (Ellingsen et al. 2003). However, a Norwegian study of SiC-producing smelters showed that 99% of the observed SiC fibers in the furnace house were <3 µm in diameter (Skogstad et al. 2006).

8. METHODS

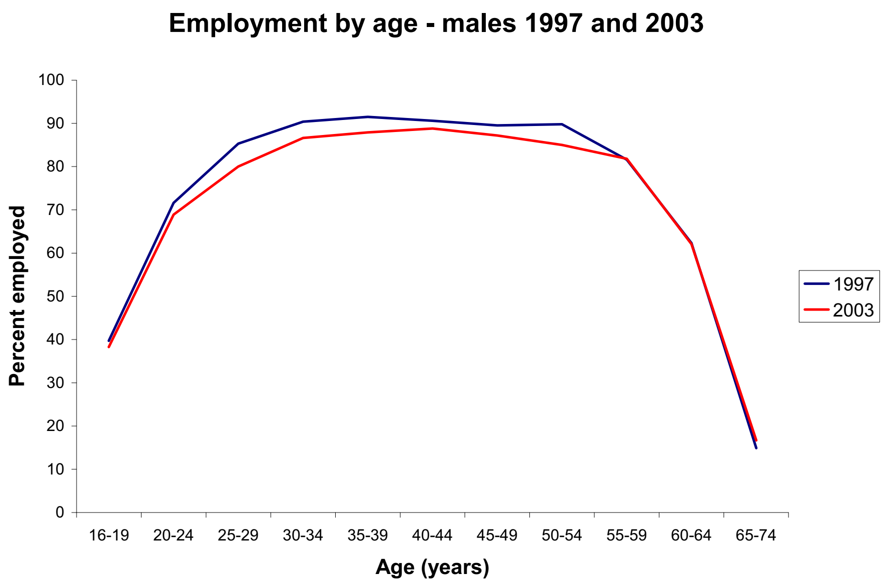
In this prospective cohort study in Norwegian smelters, the relationship between occupational exposure and respiratory symptoms, and occupational exposure and lung function was studied using both a cross-sectional and a longitudinal design.

8.1. Study population

All employees in the 24 Norwegian smelters, maintenance, and otherwise related companies, which were members of the Norwegian Federation for Process Industry in 1996 (today the Federation of Norwegian Industries), were invited to participate in the respiratory survey. At each site, the health examinations were carried out by the local occupational health services. Inclusion into the study was limited to employees aged 20-55 years at the time of the first health examination. This age range was chosen in order to reduce the number of short-term employees in the youngest age groups and the healthy worker survivor effect among the oldest. In addition, with the longitudinal design, many workers aged 57 or older by inclusion, would probably have retired (joint pension under a collective agreement possible at age 62) before the end of the study. Figure 4 shows the percentage of employed men in Norway in 1997 and 2003. The figures for women follow the same pattern but are approximately ten percent below those of men.

Written information about the study was given to each participant. Informed consent was assumed by attendance. This procedure was later approved by the Regional Committee for Medical Research Ethics, Eastern Norway.

Figure 4



Source: Statistics Norway (www.ssb.no), 2008

8.2. Study design

The participants were examined annually for five years by the local occupational health services. Each examination included spirometry and a respiratory questionnaire. Particular effort was made to include retired employees or employees on sick leave in the survey. The attendance rate was close to 90%. Table 3 shows the number of health examinations, the intervals between examinations, and the number of dropouts by year of the study. Employees who underwent their last examination more than 18 month before the end of the study were regarded as dropouts. The number of dropouts was 759 (19%) (Soyseth et al. 2008).

8.3. Questionnaires

Information on respiratory symptoms in the past year, familial asthma, former or present allergy, asthma diagnosed by a physician, previous occupational exposure, and smoking habits was collected using a self-administered questionnaire. The questionnaire used was a modification of a validated questionnaire developed for a respiratory survey in the aluminum industry (Kongerud et al. 1989). The questionnaire also recorded information on the job functions of employees in the year prior to the examination. Employees could list up to three different job titles in the questionnaire at each examination.

8.3.1. Definitions

Familial asthma was defined as present or previous asthma in a parent, grandparent, brother, or sister. Allergy was considered to be present if the employee had a history of either hay fever or atopic eczema. Doctor-diagnosed asthma was asthma diagnosed by a physician during childhood or in adulthood before the current job. Smoking habits were classified as follows: never smokers were lifelong non-smokers, former smokers had stopped smoking more than one year prior to the examination, and the remainders were classified as current smokers. Current smokers were divided into three groups: “1–9 cigarettes a day,” “10–19 cigarettes a day,” and “20 or more cigarettes a day.” For previous occupational exposure, employees were regarded as previously exposed if they answered “yes” to the question “Have you previously been exposed on a regular basis to fumes, dust or irritating vapors (gases) during your work?”

Table 3 Time at examination and intervals between examinations. The number of examinations, dropouts[a] (in parentheses) and plants (smelters and related workplaces) by year of the study.

Time	Follow-up number								Sum	
Year	Entry	1	2	3	4	5	6	7	Subjects	Plants
$\overline{T}_j$	0	1.08	2.10	3.10	3.99	4.91	4.91	4.60	-	-
$\Delta T_{j+1,j}$	0	1.05	1.06	1.02	0.98	1.03	0.89	0.60	-	-
1996	2 (0)	-	-	-	-	-	-	-	2 (0)	1
1997	2198 (92)	1 (0)	-	-	-	-	-	-	2199 (92)	21
1998	1004 (58)	2101 (111)	6 (1)	-	-	-	-	-	3111 (170)	23
1999	378 (39)	794 (47)	1884 (105)	7 (0)	-	-	-	-	3063 (191)	24
2000	171 (13)	450 (34)	726 (41)	1741 (91)	14 (0)	1 (0)	-	-	3103 (179)	23
2001	123 (6)	164 (9)	441 (87)	693 (16)	1667 (9)	15 (0)	2 (0)	1 (0)	3106 (127)	23
2002	0 (0)	77 (0)	88 (0)	190 (0)	389 (0)	828 (0)	5 (0)	0 (0)	1619 (0)	20
2003	0 (0)	19 (0)	19 (0)	46 (0)	72 (0)	197 (0)	7 (0)	1 (0)	367 (0)	13
Sum										
Subjects	3924(208)	3606 (201)	3164 (234)	2677 (107)	2142 (9)	1041 (9)	14 (0)	2 (0)	16570 (759)	-
Plants	24	24	24	23	21	17	7	2	-	-

$\overline{T}_j$: Mean time (years) after inclusion at examination j. $\Delta T_{j+1,j}$: Mean difference in time between examination j+1 and j.

[a] Employees who had their last examination more than 18 month prior to the termination of the study were regarded as drop outs.

Photo: Elkem AS

Table 4 presents the demographic data of the study population at inclusion.

Table 4 Number of subjects (N) by age, gender, familial asthma, allergy, doctor-diagnosed asthma, smoking habits, productions and previous exposure in the job categories.

	Total	Operators		Non-exposed employees
		Line	Non-line	
Age in years: Mean (range)	38.6 (20.0-55.0)	37.2 (20.0-55.0)	39.3 (20.0-54.9)	41.4 (21.7-54.8)
Males: N (%)	3472 (88.5)	1720 (94.9)	1412 (89.4)	340 (63.9)
Familial asthma[a]: N (%)	885 (22.6)	431 (23.8)	338 (21.4)	116 (21.8)
Allergy[b]: N (%)	811 (20.7)	335 (18.5)	348 (22.0)	128 (24.1)
Doctor-diagnosed asthma[c]: N (%)	313 (8.0)	142 (7.8)	127 (8.0)	44 (8.3)
Smoking status: N (%)				
Never smokers[d]	1272 (32.4)	494 (27.3)	542 (34.3)	236 (44.4)
Former smokers[e]	751 (19.1)	300 (16.6)	336 (21.3)	115 (21.6)
1-9 cigarettes/day	688 (17.5)	338 (18.7)	276 (17.5)	74 (13.9)
10-19 cigarettes/day	972 (24.8)	549 (30.3)	345 (21.8)	78 (14.7)
$\geq$ 20 cigarettes/day	130 (3.3)	80 (4.4)	39 (2.5)	11 (2.1)
Unknown	111 (2.8)	51 (2.8)	42 (2.7)	18 (3.4)
Production: N (%)				
FeSi and Si-metal	1687 (43.0)	855 (47.2)	624 (39.5)	208 (39.1)
FeMn, SiMn and FeCr	933 (23.8)	428 (23.6)	393 (24.9)	112 (21.1)
SiC	464 (11.8)	236 (13.0)	161 (10.2)	67 (12.6)
Other[f]	840 (21.4)	293 (16.2)	402 (25.4)	145 (27.3)
Previous exposure[g]: N (%)	2764 (70.4)	1452 (80.1)	1105 (69.9)	207 (38.9)
Total N (%)	3924 (100)	1812 (46.2)	1580 (40.3)	532 (13.6)

[a] Familial asthma was defined as present if the employee reported asthma in a grandparent, parent, brother or sister.
[b] Allergy was considered present if the employee reported a history of hay fever or atopic eczema.
[c] Doctor-diagnosed asthma was previous or current asthma diagnosed by a physician before the current job.
[d] Never smokers were lifelong non-smokers.
[e] Former smokers were defined as smokers who had stopped smoking more than one year prior to the examination.
[f] Titanium oxide (TiO_2), calcium carbide (CaC_2) and Ceramite production together with the electrode paste production plant and research and maintenance firms serving the smelters.
[g] Previous exposure was defined as exposure to dust, fumes or gases before current job.

8.4. Spirometry

Spirometry was performed as recommended by the European Community for Steel and Coal (ECSC) (Quanjer et al. 1993).

Before the start of the study, a written protocol was created describing spirometric procedures and interpretation of the spirometric results. This protocol was given to all the technicians who carried out the spirometry in the study. The same technicians also completed a one-day course in lung function testing, encompassing spirometric performance guidelines, calibration, and interpretation. This course was led by one of the investigators (Johny Kongerud). Regular follow-up courses for evaluation were conducted, with the importance of calibration and technique particularly stressed.

The spirometers used in the study fulfilled the specifications of the ATS and ECSC (ATS 1991; Quanjer et al. 1993). Spirometers were volume-calibrated daily, and every week a biological calibration was performed with the same person each time. If the temperature changed by more than 2˚C during a day of examination, calibration was repeated.

The yearly spirometry was conducted, preferably in autumn, in the sitting position using a nose clip. Employees rested for 15 minutes before measurement. Each subject performed at least three FVC maneuvres. The maximum acceptable variation between the best and second-best measurement of FVC was 5% or 100 ml, whichever was highest. Employees should not have used a short-acting β-2-agonist inhaler in the four hours prior to spirometry; in addition, they were not allowed to eat or smoke one hour prior to the test.

The FVC and FEV_1 values in percent of predicted were calculated according to the ECSC reference values (Quanjer et al. 1993).

8.4.1. Reversibility test

Employees with an FEV_1 less than 80% of predicted or an FEV_1/FVC ratio less than 14% below the predicted value (approximately two standard deviations (SD) from the mean) were offered a reversibility test. The medications used for the reversibility test were either two inhalations of a β-2-agonist or ipratropium bromide. Spirometry was repeated

20 minutes after β-2-agonist inhalations and 45 minutes after inhalation of ipratropium bromide.

A reversibility test was regarded as positive if an increase in FVC or FEV_1 of 12 % of the predicted normal value and an absolute increase of at least 200 ml in FVC or FEV_1 were observed (ATS 1991).

8.4.2. Airflow limitation

The practice of using 0.70 as the lower limit of the FEV_1/FVC ratio has been questioned in recent years, as it has been shown that the use of the fixed ratio underestimates airflow obstruction in 20 to 49 year-old individuals and overestimates it in the elderly (Hardie et al. 2002; Hnizdo et al. 2006). The analyses in the present study (Paper II) were therefore performed using FEV_1/FVC below the 5^{th} percentile of the predicted value as the lower limit for FEV_1/FVC (LLN FEV_1/FVC) (Pellegrino et al. 2005; Hansen et al. 2007). Airflow limitation was defined as FEV_1/FVC below LLN FEV_1/FVC.

8.5. Exposure classification

In epidemiologic studies, exposure can be classified using different methods (Stewart et al. 1996; Checkoway et al. 2004). In this study both a qualitative and a quantitative exposure classification were constructed. Analyses using the qualitative exposure classification were made for all the 24 smelters and related workplaces (Papers I, II, and III), while analyses using the quantitative exposure classification (JEM) were restricted to the FeSi/Si-metal and SiMn/FeMn/FeCr producing smelters (Papers IV and V). The qualitative exposure classification was evaluated against the JEM (Paper IV).

8.5.1. Qualitative exposure classification

The qualitative exposure classification of employees was based on their job functions in the year prior to each health examination. Employees were classified into three exposure categories: *line operators* were those working full time on the production line, *non-exposed employees* were those working full time outside production, and the remainder were classified as *non-line operators* (Figure 5). The "production line" was defined as production from the handling of raw materials inside the plant to crushing, screening, and packing of end products. *Line operators* performed the following jobs: handling and mixing of raw materials before charging the furnaces, all full-time jobs in the furnace house, and crushing, screening, and packing of end products. *Non-exposed employees* were primarily full-time office staff. *Non-line operators* included the remaining employees, loading and unloading raw materials and end products outside the plant, and employees working part time on the production line, such as foremen, maintenance, and laboratory workers. Each exposure category was coded using two dummy variables as shown in figure 5.

Figure 5 Production sites by exposure classification using two dummy variables.

Exposure CLASSIFICATION	Import and unloading	Handling of raw materials	Furnace House	Crushing and packing	Export and loading
Full time					
LINE OPERATOR	0	1	1	1	0
NON-LINE OPERATOR	1	0	0	0	1
Part time					
LINE OPERATOR	0	0	0	0	0
NON-LINE OPERATOR	1	1	1	1	1
None					
LINE OPERATOR	0	0	0	0	0
NON-LINE OPERATOR	0	0	0	0	0

An employee who had more than one job in the previous 12 months was classified as a line operator if he or she was classified as a line operator in all jobs held during the entire period. Similarly, an employee was classified as non-exposed only if he or she was classified as non-exposed in all jobs held in the previous 12 months. The remaining employees were classified as non-line operators. In the 16 570 health examinations of employees aged 20-55 years at inclusion to the study, more than one job title was registered at 1686 examinations (10.2%).

Classification of each of the reported job titles into one of the three categories – line operator, non-line operator, or non-exposed employee – was made by two industrial hygienists with extensive knowledge of the smelting industry, Erle Grieg Astrup and Siri Merete Hetland (SMH). At the time of classification the industrial hygienists did not know the dust exposure concentration levels, smoking habits, previous exposure, or health status of the employees. Consensus was reached by discussion while classifying the subjects. The qualitative exposure classification was reviewed by the author (HLJ), similarly blinded for exposure and health outcome.

8.5.2. Quantitative exposure classification – the JEM

A job exposure matrix (JEM) was developed for the production groups FeSi/Si-metal and SiMn/FeMn/FeCr. For the SiC production group the JEM was developed by Merete Drevvatne Bugge, at the National Institute of Occupational Health (NIOH).

Exposure measurements performed in the smelters between 1990 and 2004 were recorded. A total of 5557 such exposure measurements were registered for the 15 smelters included in the FeSi/Si-metal (11 smelters) and SiMn/FeMn/FeCr (four smelters) production groups. They encompassed both personal and stationary measurements and included measurements of respirable and so-called total dust, polycyclic aromatic hydrocarbons (PAH), carbon monoxide (CO), and sulfur dioxide (SO_2). However, as the number of measurements of PAH, CO, and SO_2 were low and originated from only a few of the smelters, it was decided that the JEM should represent personal "total dust" measurements performed during the study period 1996 to 2004.

More than 70% of the industrial hygiene dust exposure measurements in the FeSi/Si-metal production and the FeMn/SiMn alloy production were part of investigations performed by NIOH. The remaining dust exposure data originated from routine sampling programs in the smelters and were analyzed by three different laboratories serving the smelters.

8.5.2.1. Sampling and calculation of exposure estimates

So-called total dust was collected at a sampling rate of 2 L/min on mixed cellulose filters (AAWP, Millipore Corporation, Mass., USA) with an 0.8 µm pore size, fitted in 25 or 37 mm closed-faced three-part plastic cassettes (MP cassettes). The particle mass was measured using a microbalance (Sartorius AS, Goettingen, Germany) with a detection limit of 0.06 mg.

The MP cassette used in this study has been widely used for sampling so called total dust. The sampling efficiency for particulates (aerosols) of this cassette seems to be closer to the thoracic fraction than to the inhalable fraction (CEN 1993: NS-EN 481). However, for particulates with aerodynamic diameters > 15 µm, this cassette overestimates the thoracic fraction (Vincent J. 1995; Kenny et al. 1997). This means that in samples including particulates with a diameter > 15 µm, the measured concentration level is higher than the true level of particulates.

The dust concentration measurements made were assessed as representative for the whole study period, as the measurements were performed randomly during the period and only minor changes in production and abatement technology were introduced. This assumption was confirmed by analyses of time trend regarding job titles, departments, smelters, and production groups using mixed models analyses. No time trend was found for production groups (Paper IV). For the smelters, a time trend was found for 2 of the 15 smelters. We therefore examined the time trend regarding job titles in the different smelters. It was found that where a time trend seemed to exist (a total of two different job titles in two smelters) this was due to fewer than 10 measurements (3–9 measurements). We therefore find it justified to consider the measurement data to be representative of the entire study period.

Of the 4234 personal dust exposure measurements performed in the FeSi/Si-metal and SiMn/FeMn/FeCr production groups, only samplings by MP cassette were used for the development of the JEM. Measurements made by MP cassettes were available in 13 smelters ($N_{MP\text{-}cassette}$=2680). Of the remaining 1554 personal measurements, 1497 were performed with IOM samplers (Institute of Occupational Medicine, Edinburgh, UK), as part of a study comparing results obtained with MP cassettes and IOM samplers (Hetland 2005, personal communication).

Samples with a dust concentration level exceeding 50 mg/m^3 were excluded as they were considered invalid due to sampling errors, as assessed by the industrial hygienist (SMH), who has conducted exposure measurement projects in both the FeSi/Si-metal and SiMn/FeMn/FeCr production groups and has extensive knowledge of the Norwegian smelting industry. The number of excluded samples was as follows: N=20, range 50 – 1905 mg/m^3, standard deviation (SD) 415 mg/m^3.

The average length of an employee's work shift during the study period was 480 minutes. Measurements with a sampling period of less than 240 minutes were excluded (N=41, range 0.21–94 mg/m^3, SD 18 mg/m^3). Of the included measurements, 86% were recorded either as "full-shift" measurements or had a duration of 420 minutes or more. As such the included industrial hygiene measurements were considered by the industrial hygienist (SMH) to be representative for the whole work shift and were not transformed into eight-hour time-weighted averages.

If the measured personal dust exposure concentrations were less than the detection limit (3.5% of the measurements), the results were substituted by a concentration level equal to half of the detection limit.

Finally, the data set used for the construction of the JEM consisted of 2619 personal dust exposure measurements. The arithmetic mean (AM) and geometric mean (GM) dust concentration level of these measurements was assigned to the corresponding exposure group (smelter/department/job title) provided that five or more dust measurements were available. When fewer than five measurements were available for a given exposure group, the group was assigned the AM and GM dust exposure level of the respective job title in all smelters of the production group (FeSi/Si-metal or SiMn/FeMn/FeCr).

For some departments (filter, electrode, refractory, laboratory, and CSP) it was not possible to distinguish between job titles (one to three job titles per department), as all the tasks in the department were generally performed by all the employees of the department. In each of these departments, we used the AM and GM dust level of the department as a whole for all the job titles in the department.

When fewer than five measurements were available for a given department in a smelter, we used the AM and GM dust levels of the respective department in the production group including the measurements of the respective smelter.

Employees in administration departments, who were regarded as non-exposed ("office work only" in table 1), were assigned 1% of the AM and GM dust exposure concentration of all departments (excluding electrode and refractory departments) of the respective smelter. Employees regarded as "partly exposed," such as administrative personnel with part-time supervision in production, were assigned 10% of the AM and GM dust exposure concentration of the smelter. As there was only one personal dust exposure measurement for "maintenance cleaner", the exposure for this job title was assessed as half the exposure of the smelter (excluding the electrode and refractory departments).

The job titles of the furnace house were distinguishable in all the measurement data, but were only fully distinguishable in 5 out of 15 smelters in the job titles obtained from the respiratory questionnaire. As such, in 10 out of 15 smelters, we were not able to differentiate between tappers, furnace operators, and other job functions held by the operators in the furnace house section due to a lack of specificity in the work histories. In these smelters a new job title "furnace section worker" was created and the dust exposure concentration for this job title was estimated as the AM and GM of all the included dust measurements of the respective furnace house. Mixed model analyses performed using the measured dust exposure concentration levels in the 10 smelters with indistinguishable job titles showed that there was a significant difference between the dust exposure levels of tappers and furnace operators. Consequently, construction of the job title "furnace section worker" led to misclassifications regarding dust exposure levels of employees in the furnace house of these smelters.

8.5.2.2. Exposure groups for the JEM

Each exposure group was defined by a unique combination of smelter, department, and job title. We used a classification system of job titles and departments developed by Elkem AS (PEKSI – Pilot exposure database for Si-metal and FeSi production). The matrix included 15 smelters, with each smelter divided into departments (5–10 departments per smelter) encompassing 49 different job titles (6–16 job titles per smelter). As the job titles were unique for the different departments, this resulted in 222 unique exposure groups (smelter/department/job title). In table 1, ten of the departments are shown; the remaining four departments were departments located only in one of the smelters. Similarly, 19 of the 49 job titles are shown. Even if not shown in table 1, the specified exposure groups with their allocated dust exposure levels were used in the analyses.

8.5.2.3. Allocation of exposure for employees

At each health examination up to three job titles could be recorded for each of the 2620 employees participating in the respiratory survey in the FeSi/Si-metal and SiMn/FeMn/FeCr production groups. This resulted in 13 166 individual registrations among the 11 335 health examinations performed over the study period.

The 222 unique combinations of smelter, department, and job title with a specific dust exposure concentration level were assigned to the employees as follows: where an employee had held more than one job in the 12 months prior to the health examination, the AM and GM of dust exposure for the employee were calculated weighted by the time spent in each of the jobs (with a maximum of three job titles). For time periods of no employment in the industry, i.e., employees on leave, the employee was assigned an exposure of zero.

As shown in table 5, a direct link between the employee job title (smelter/department/job title), collected during the respiratory survey, and the JEM exposure group was achieved for 4454 individual registrations (33.8% of all registrations). In 3881 individual registrations (29.5%), exposure was based on the dust exposure concentration of the corresponding department. Due to an inability to make a direct link (job title or department), exposure in 1687 registrations (12.8%) was based on the dust exposure concentration of the respective job title or department in the production group, and in 25 registrations (0.2%) the dust concentration of the respective job title or department in all the smelters (both FeSi/Si-metal and SiMn/FeMn/FeCr) was used. The remaining 3127 registrations (23.8%) represented non-exposed and partly exposed employees as well as retired employees and those on leave. Thus, a direct link between the job title of employees and the dust exposure of the job title or department in the particular smelter was achieved for 87% of workers.

Table 5 Employees in production groups and observation time by link category.

	All			FeSi/Si-metal			SiMn/FeMn/FeCr		
	N	%	T	N	%	T	N	%	T
Direct link									
Job title	4454	33.8	3617.6	2011	25.4	1812.9	2443	46.5	1804.7
Department	3881	29.5	3547.5	2810	35.5	2574.4	1071	20.4	973.1
Non- and partly exposed[1]	3117	23.8	2624.7	1948	24.6	1661.8	1169	22.2	962.8
Estimated dust exposure									
Average production group	1687	12.8	1521.7	1143	14.4	1053.8	544	10.4	464.9
Average all	25	0.2	21.5	-	-	-	25	0.5	21.5

N=number of employees. %=percent of total number of employees in the cohort. T= observation time in the study (years).
[1] This group included all non-exposed employees (dust exposure estimated as 1% of the AM and GM dust exposure of all departments of the smelter, excluding electrode and refractory departments), partly exposed employees (dust exposure estimated as 10% of the AM and GM dust exposure of the smelter), and employees on leave or retired.

Photo: Elkem AS

8.5.3. Exposure estimates

Figures 6 and 7 show box plots of dust exposure by production group and job classification. Due to a lack of information on dust exposure for all job titles in Odda smelteverk, this smelter is not included in the illustrations (figure 6 and 7). For one smelter in the group of Other, the included measurements were performed by cyclone (respirable dust). Only samples with a dust exposure level below 50 mg/m^3 were included.

Boxplot (Tukey 1977): The median of the dust exposure is indicated by the black center line, and the first and third quartiles are the edges of the orange area, i.e., the interquartile range (IQR), meaning that the box represents half of the dust exposure values. The extreme values (within 1.5 times the IQR from the upper or lower quartile) are the ends of the whiskers. Values at a greater distance from the median than 1.5 times the IQR (outliers) are plotted individually as droplets.

Figure 6 Time-weighted "total dust" exposure in the production groups.

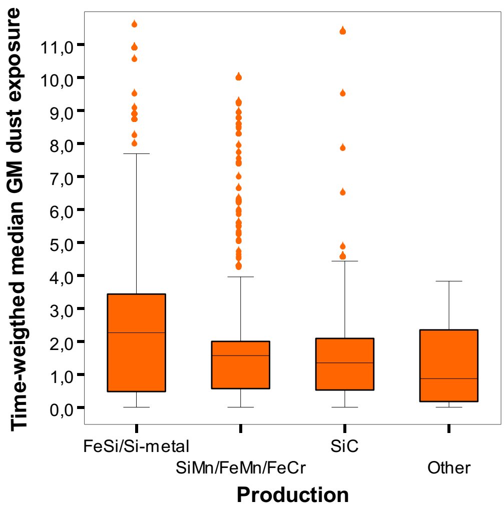
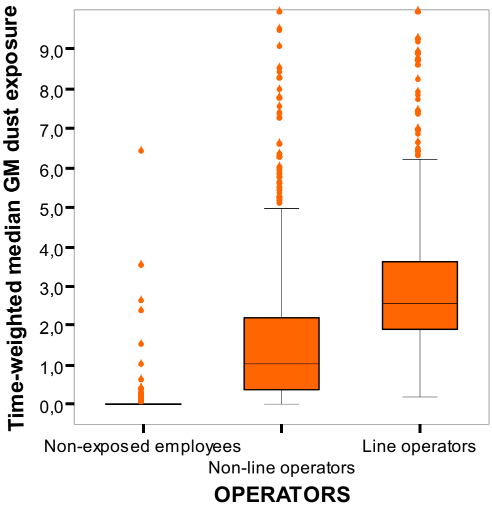


Figure 7 Time weighted "total dust" exposure for non-exposed employees, non-line operators, and line operators.



8.6. Statistical analyses

In this observational longitudinal study the outcome variables were influenced by several factors. Consequently, multivariate analyses were chosen in order to control for confounding and interaction (Altman 1999).

Multivariate logistic regression analyses were performed with respiratory symptoms and airflow limitation as outcome variables in the cross-sectional analyses (Papers I and II). The multivariate logistic regression model was reduced using the log-likelihood test in backward elimination. The global goodness-of-fit of the model was evaluated using the Hosmer-Lemeshow test. To assess outliers, analyses of studentized residuals were performed.

In the cross-sectional study the continuous outcome variables, FEV_1 and FVC, were modeled using ordinary least square regression (Paper II). Age was centered to 38.6 years, the average age of the participants at inclusion to the study. The quadratic term of centered age was included, as this reflects the biological events better than age itself

(Gulsvik et al. 2001). The initial model was reduced by backward elimination using the partial F-test for nested models. Non-significant covariates were removed from the model unless they were covariates of interest or their removal caused a meaningful change between the outcome and the covariates. Tests for trend in the multiple regression models were performed by including the categorized variables.

The longitudinal data analyses (Papers III, IV, and V) were performed using a linear mixed effect model for continuous outcomes, which allows data to be unbalanced (Sherrill and Viegi 1996; Fitzmaurice et al. 2004). First, the covariates of interest including product terms among the different covariates and the appropriate time variable were selected. Next, several covariance matrices for the fixed effects were considered and models including random effects for intercepts and slopes were fitted using unstructured covariance. Finally, models containing both fixed and random effects were investigated. Each model was reduced by elimination of insignificant covariates, unless removal caused a meaningful change (>20%) of the association between outcome and the variable of interest. The Akaike Information Criterion (AIC) was used for model selection (Sherrill and Viegi 1996). Lung function was expressed as FEV_1/height^2 (papers III and V) as this resulted in a lower AIC than FEV_1 itself, which is in line with other studies (Ware and Weiss 1996; Hendrick et al. 2005). In agreement with Vestbo et al., we also found that the combination of age at inclusion and time of the study gave a better fit to the data than the age at each examination (Vestbo et al. 1999).

To investigate the time trend for binary outcomes (Paper III), Generalized Estimation Equations (GEE) were used (Zeger and Liang 1986).

In order to adjust for differences between the smelters, the smelters were included in the models using a dummy variable for each smelter (23 dummy variables).

Analyses were performed using the Statistical Package for the Social Sciences (SPSS Inc., Chicago, version 12.0.1 and 14.0.2), SAS PROC MIXED and SAS PROC GENMOD (SAS Institute Inc., Cary, SAS version 9.1).

9. RESULTS

9.1. Respiratory symptoms

An increased prevalence of dyspnea, cough without a cold, cough for more than three month in the past 12 months, and phlegm when coughing was indicated among line operators compared with non-exposed employees (odds ratio (OR)=1.1–1.9). However, the multivariate logistic analyses revealed that except for cough (OR=1.3; 95% confidence interval (CI): 1.0–1.8), and phlegm (OR=1.9; CI: 1.4–2.7), these associations were not significant. The OR of any respiratory symptom in relation to previous exposure compared with no previous exposure was significantly increased (OR=1.3–1.7) and exceeded the OR for respiratory symptoms in line operators except for phlegm (Paper I).

The multivariate logistic analyses in regard of the respiratory symptoms dyspnea, dyspnea and wheeze, cough without a cold, cough for more than three month, and phlegm revealed that apart from "dyspnea and wheeze" none of the models included any significant interaction terms between job category and previous exposure. Therefore, the association between "dyspnea and wheeze" and covariates were analyzed separately regarding previous exposure (Paper I). These analyses showed that for line operators not reporting previous exposure to dust, fumes, or gases the OR for "dyspnea and wheeze" was 4.1 (CI: 1.8–9.6) compared with non-exposed employees. The corresponding OR among previously exposed line operators were 1.0 (0.6–1.6).

9.2. Familial asthma, allergy, and doctor diagnosed asthma

At inclusion to the study, reporting of familial asthma and doctor-diagnosed asthma was significantly associated with all respiratory symptoms (OR=1.6–2.9), with lower FVC, –74 ml (95% CI: –120 to –29) and –111 ml (–181 to –40), respectively, and lower FEV_1, –80 ml (–119 to –41) and –173 ml (–232 to –113), respectively (Papers I and II). Reported allergy was found to be significantly associated with increased prevalence of "dyspnea," "dyspnea and wheeze," and "cough without a cold" (OR=1.6 (1.3–1.9), OR=1.7 (1.4–1.22), and OR=1.5 (1.2–1.8), respectively), but was not significantly associated with the level of FVC, FEV_1, or FEV_1/height^2 (Papers I, II, and V).

The longitudinal analyses using the qualitative exposure classification revealed a strong negative association between doctor-diagnosed asthma and the level of FEV_1/height^2,

–17.2 ml/m^2 (p-value=0.002) (Paper III). However, the product term between doctor-diagnosed asthma and time was not significant, indicating that employees with asthma did not have an accelerated annual decline in FEV_1/height^2 compared with those not reporting doctor-diagnosed asthma. In the longitudinal analyses of the relationship between dust exposure and FEV_1/height^2, a relationship between familial asthma and the level of FEV_1/height^2 was found, –12.3 ml/m^2 (p-value=0.0004) (Paper V). However, the product term of familial asthma and time was not significant. In the same analyses no significant association between doctor-diagnosed asthma or allergy and level of FEV_1/height^2 was found. The product term of allergy and time was not found to be significant in the longitudinal analyses (Paper V).

9.3. Body weight and lung function

Body weight was found to be associated with level of FEV_1 in both the cross-sectional and longitudinal analyses (Papers II, III, and V). However, weight was not found to be associated with an accelerated annual decline in FEV_1 (Papers III and V). Univariate analysis of weight versus time since inclusion using mixed model analyses revealed a weight gain in the employees of 0.43 kg×year^{-1} (range 0.38 to 0.48) over the study period (Paper III).

Figure 8 presents the relationship between FVC and FEV_1 as percent of predicted and weight category of the male employees at the time of inclusion. An increase followed by a decrease was indicated for both FVC and FEV_1 as percent of predicted in relation to weight category. A similar pattern was observed for the predicted values of FVC and FEV_1 using body mass index (BMI) as independent variable. In female employees, the relationship between weight category, BMI, and lung function did not show the same pattern (figure 9). In the cohort of male workers at Norwegian smelters, both high and low body weight seemed to be associated with lower FVC and FEV_1.

Figure 8. FVC and FEV_1 in percent of predicted related to weight category in males. Standard deviation (SD) presented by whiskers.

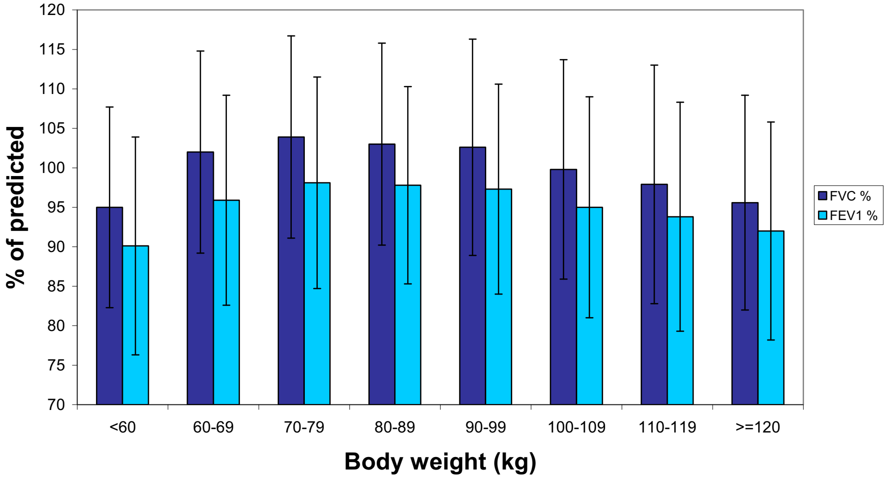
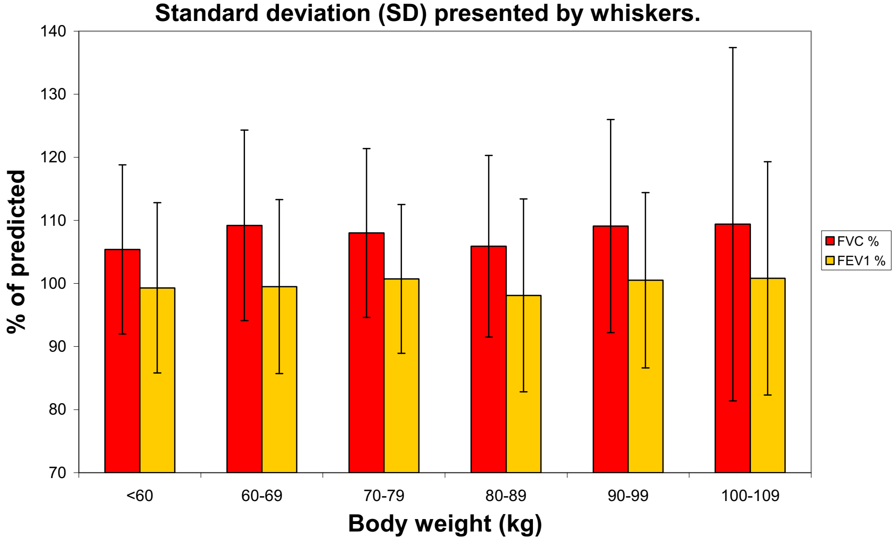


Figure 9. FVC and FEV1 in percent of predicted related to weight category in females. Standard deviation (SD) presented by whiskers.



9.4. Previous exposure

At inclusion to the study, employees reporting previous exposure to dust, fumes, or gases were found to have significantly more respiratory symptoms such as dyspnea, cough, cough for more than three month, and phlegm than employees without such previous exposure (Paper I). However, previous exposure to dust, fumes or gases was not found to be associated with employee's FVC or FEV_1 levels (Paper II).

Dust exposure concentration levels were found to be higher in employees with previous exposure to dust, fumes, or gases than in those without previous exposure, though this was only significant in the FeSi/Si-metal production group (Paper IV).

In the longitudinal analyses of dust exposure and $FEV_1/height^2$, the product term of dust exposure and previous exposure was significantly associated with the level of $FEV_1/height^2$ in the total cohort and in the FeSi/Si-metal production group (Paper V). The analyses were therefore performed stratified for previous exposure in the FeSi/Si-metal production group. For previously exposed employees in this group, the annual change in $FEV_1/height^2$ related to dust exposure was –0.19 (95% CI: –0.80 to 0.42) $(ml/m^2)\times(mg/m^3)^{-1}\times year^{-1}$; for employees not reporting previous exposure the annual change in $FEV_1/height^2$ was –1.2 (–2.4 to –0.044) $(ml/m^2)\times(mg/m^3)^{-1}\times year^{-1}$.

9.5. Lung function and exposure

At inclusion to the study the multivariate analyses showed that, compared to FEV_1 in non-exposed employees, FEV_1 was 87 (95% CI: 33–141) ml and 65 (12–118) ml lower in line and non-line operators, respectively (Paper II). The prevalence of airflow limitation (FEV_1/forced vital capacity (FVC) below the 5th percentile of the predicted value) was 4.7% in non-exposed employees, 7.5% in non-line operators, and 8.3% in line operators (Paper II).

In the longitudinal analyses using the qualitative exposure classification we found that the annual decline in $FEV_1/height^2$ among line operators in the FeSi/Si-metal and SiC production groups was significantly steeper than the annual decline among non-exposed employees. A 1.80 m tall line operator could expect a 7.5 ml/year (FeSi/Si-metal) and

18.1 ml/year (SiC) faster decline in FEV_1 than non-exposed employees in the same production groups (Paper III).

Regarding dust exposure concentration levels, we found that in the FeSi/Si-metal production group the median GM of dust exposure was 2.3 mg/m^3 (10 to 90 % percentiles: 0.04–5.6) compared with 1.6 mg/m^3 (0.02–2.3) in the SiMn/FeMn/FeCr production group (Paper IV).

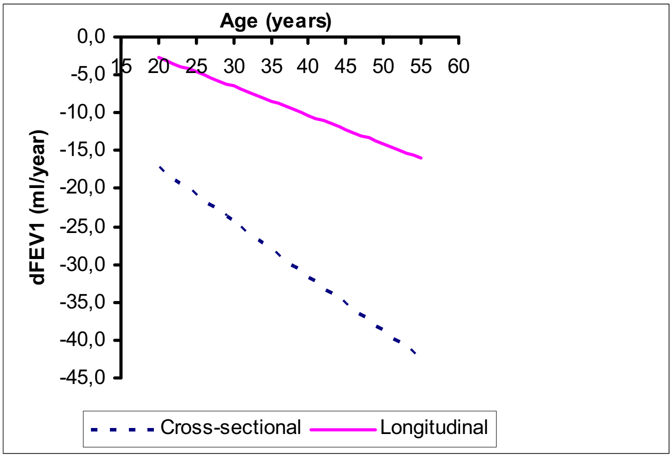
In the longitudinal analyses using the quantitative JEM for exposure classification we found that the annual change in $FEV_1/height^2$ (δFEV_1) regarding dust exposure was –0.49 (–0.94 to –0.039) $(ml/m^2)\times(mg/m^3)^{-1}\times year^{-1}$ (Paper V). In the FeSi/Si-metal and SiMn/FeMn/FeCr smelters, δFEV_1 was –0.42 (–0.95 to 0.11) $(ml/m^2)\times(mg/m^3)^{-1}\times year^{-1}$ and –1.1 (–2.1 to –0.12) $(ml/m^2)\times(mg/m^3)^{-1}\times year^{-1}$, respectively. In current smokers δFEV_1 was –1.6 (–3.1 to –0.15) $(ml/m^2)\times(mg/m^3)^{-1}\times year^{-1}$ compared with non-smokers. Among non-smokers, δFEV_1 was –0.86 (–1.6 to –0.10) and –1.1(–2.5 to 0.25) $(ml/m^2)\times(mg/m^3)^{-1}\times year^{-1}$ in the FeSi/Si-metal and SiMn/FeMn/FeCr smelters, respectively. In a non-smoking, 1.80 m tall employee working in FeSi/Si-metal production with an average exposure of 2.3 mg/m^3, this would represent a decline of 6.4 ml/year due to dust exposure. In the SiMn/FeMn/FeCr production group, the annual decline due to dust exposure was 5.8 ml/year with an average exposure of 1.6 mg/m^3.

9.6. Annual decline in FEV_1: Cross-sectional versus longitudinal design

Discordance between annual decline in FEV_1 estimated from cross-sectional and longitudinal analyses has been described in previous studies (Lebowitz 1996; Hendrick et al. 2005). It was therefore of some interest to investigate the annual decline in FEV_1 using both a cross-sectional and a longitudinal approach. The data presented in paper II and III were used for the analyses.

The annual change in FEV_1 was lower and decreased more rapidly with increasing age when estimated cross-sectionally than longitudinally (figure 10).

Figure 10 Annual decline in FEV_1 by age.



9.7. Current smoking

Current smoking was significantly associated with both increased prevalence of all respiratory symptoms and a lowered dose-dependent level of FEV_1 at inclusion (Papers I and II).

As shown in table 6, the prevalence of current smoking decreased during the study period. The proportion of never-smokers was almost constant over the course of the study, while the proportion of former smokers increased (Paper III). As expected, current smoking was found to be associated with an increased annual decline in $FEV_1/height^2$ compared with non-smoking. Current smokers 1.80 m tall were found to have an excess yearly decline in FEV_1 of 6.5 ml (Paper III) and 5.2 ml (Paper V).

For currently smoking line operators, the GM of dust exposure levels was 3.5 mg/m^3 above that of non-exposed employees, whereas the GM of dust exposure levels of never-smoking line-operators was 3.2 mg/m^3 above that of non-exposed employees (Paper IV). In the present study no multiplicative effect of smoking and occupational dust exposure was shown.

Table 6 Prevalence of smoking and level of body weight over the study period by job category.

	Follow-up number					
	entry	1	2	3	4	5
Current smokers, N (%)	1520 (47.6)	1383 (47.2)	1177 (46.0)	1019 (44.8)	782 (41.9)	396 (39.6)
Non-exposed employees	136 (31.3)	134 (32.8)	109 (32.3)	90 (30.9)	72 (30.4)	36 (26.7)
Non-line operators	574 (43.7)	574 (45.4)	534 (43.7)	441 (41.7)	361 (38.9)	189 (36.5)
Line operators	810 (56.0)	675 (53.8)	534 (53.5)	488 (52.8)	349 (49.9)	171 (49.1)
Body weight, kg (SD)	82.9 (14.2)	83.5 (14.4)	83.9 (14.6)	84.3 (14.8)	84.9 (14.6)	85.8 (14.9)
Non-exposed employees	80.0 (15.2)	81.0 (15.5)	81.3 (15.4)	81.2 (16.4)	81.1 (16.3)	81.9 (16.4)
Non-line operators	82.8 (13.9)	83.5 (14.0)	83.9 (14.6)	84.1 (14.2)	85.1 (14.2)	86.8 (14.9)
Line operators	83.8 (14.0)	84.3 (14.3)	84.6 (14.1)	85.4 (14.8)	86.0 (14.5)	85.7 (14.3)

As only a small number of employees were examined more than 6 times, only the figures for the first six health examination are presented.

Photo: Tinfos Titan & Iron, Tyssedal

10. DISCUSSION

This thesis is based on a prospective cohort study of the relationship between occupational exposure in the Norwegian smelting industry and lung function and respiratory symptoms.

10.1. Methodological considerations

10.1.1. Study design

In this thesis both cross-sectional and longitudinal analyses were used. Cross-sectional studies or prevalence studies provide information about the cohort at a specific point in time, and the association between the outcome and current or previous exposure can be studied (Checkoway et al. 2004). Thus, such studies provide information about the prevalence of a certain outcome, but not about incidence (Miettinen 1982; Rothman 2002). The main objection against cross-sectional studies is that large selection biases can affect the validity of the results (Checkoway et al. 2004). However, cross-sectional studies are considerable cheaper and less time consuming than longitudinal studies, and can be used to describe the cohort at inclusion to longitudinal studies.

In a prospective cohort study, individuals who are initially healthy are enrolled and the development of disease over time is observed (Hennekens and Buring 1987). Thus, this design is best suited to investigation of relatively common outcomes that will ensue in sufficiently large numbers over a reasonably short period of time (Altman 1999; Checkoway et al. 2004). The main advantage of prospective cohort studies is the possibility to examine multiple effects of exposure together with the ability to measure changes in outcomes using the individual as his or her own control (Hennekens and Buring 1987; Twisk 2003). The main limitations are that this type of study can be very expensive, time consuming, and difficult to analyze (Twisk 2003). A further limitation that should be taken into account when analyzing longitudinal data is that longitudinal studies are susceptible to survivor bias (Eisen et al. 1995; Altman 1999; Radon et al. 2002; Hendrick et al. 2005).

For the present prospective cohort study, a study period of five years was chosen with annual health examinations. At least two measurements are required to assess a possible trend when using mixed model analyses (Twisk 2003). In cohort studies the major source of bias relates to the necessity of following individuals for a period of time to determine the development of the outcome of interest (Hennekens and Buring 1987; Altman 1999). If the proportion of those lost to follow-up is large, i.e., in the range of 30–40 percent, the validity of the results may be questioned (Hennekens and Buring 1987). However, even a lower proportion lost to follow-up may be of concern if the probability of loss is related to the exposure, the outcome, or both. As shown in table 3, the number of dropouts in the present study was modest, 759 (19.3%). Analyses showed that the annual decline in $FEV_1/height^2$ did not differ between those who were lost to follow-up and those who completed the study (Paper III). Determinants of loss to follow-up in the present cohort have been further investigated in a separate study (Soyseth et al. 2008). In that study, in relation to dropping out, we found that symptoms reported at the end of follow-up were generally more significant than symptoms reported at inclusion. Likewise, reduced lung function (FEV_1/FVC < LLN) at the end of follow-up was an independent predictor of dropping out from the study. This suggests that current symptoms and airflow limitation are more important regarding “loss to follow up” than symptoms and airflow limitation at enrollment. Nevertheless, as dropout accumulates during the study, this might be of importance for the results of the longitudinal study. We therefore compared the annual decline in $FEV_1/height^2$ between dropouts and those who remained in the study (Paper III). Separate models were used for line operators, non-line operators, and non-exposed employees. The difference in annual change in $FEV_1/height^2$ between dropouts and stayers was –0.7 (range: –6.7 to 5.4), –1.5 (–6.7 to 3.7), and 4.8 (–2.6 to 12.3) $ml \times m^{-2} \times year^{-1}$ in line operators, non-line operators, and non-exposed employees, respectively. Thus, in the present study, the decline in $FEV_1/height^2$ did not differ significantly between those who stayed in the study and those who were lost to follow-up.

Previous studies examining both the longitudinal and cross-sectional estimates of decline in FEV_1 have shown a steeper annual decline when using a cross-sectional approach than when using longitudinal analyses (Sherrill et al. 1992; Lebowitz 1996; Hendrick et al. 2005). This is in accordance with our findings that the annual decline in FEV_1 estimated from cross-sectional data was steeper than the annual decline in FEV_1 estimated from longitudinal analyses. This difference between cross-sectional and longitudinal approaches to the age-lung function relationship is thought to be mainly due to a cohort effect (Lebowitz 1996).

10.1.2. Selection of control group

The paradigm of an epidemiological study is the randomized clinical trial (RCT), where participants are selected through the inclusion criteria and then randomized to either exposure or non-exposure (Hill 1953; Miettinen 1989). In an occupational epidemiological study, this ideal goal can best be achieved by using an internal control group of employees with comparable non-exposure (Rothman 2002). In the present study, as controls we used the group of employees not exposed in production during the study period, i.e., office workers. However, this approach does not guarantee complete comparability of characteristics of the control group and the index group. First, selection bias may be present, as it is likely that compared with subjects without respiratory problems subjects with airway disease will seek employment in less exposed jobs, and subjects who develop airway diseases in an exposed job will be more likely to transfer to less exposed posts. The finding in our study that the prevalence of allergy and doctor-diagnosed asthma was highest in the non-exposed group at inclusion might be due to selection (Paper I). The selection of healthy workers into the workforce and the keeping of the healthiest workers in the most exposed jobs has been described to great extent over the years (Baillargeon 2001; Radon et al. 2002). In addition, there may be social and educational differences between the various groups of employees. However, in the Norwegian smelting industry the majority of workers are skilled, salary differences between employees are relatively small, and the housing standard of the employees is high. Thus, socioeconomic differences are thought to be of minor importance in the present cohort. Although the present study design cannot adjust for the above-mentioned factors, these factors would probably tend to weaken the association between exposure and health outcome (Kleinbaum et al. 1982). Consequently, we do not think that our findings are overestimated.

10.1.3. Exposure assessment

10.1.3.1. Qualitative exposure classification

Assessment of the qualitative exposure classification was made based on employee's job titles by two industrial hygienists without any knowledge of the employees' answers to the respiratory questionnaire or their lung function tests. Therefore, eventual misclassification is thought to be non-differential, i.e., random. Such non-differential misclassification would tend to weaken the relationship between exposure, expressed by job classification, and health outcome (Goldberg et al. 1993).

The classification of the employees into only three groups with presumed different exposure may appear simple. However, classification into "white collar" and "blue collar" workers has been widely used in occupational epidemiologic studies (Heederik et al. 1990). In the present study, non-exposed employees resemble "white collar" workers, and non-line and line operators resemble "blue collar" workers.

Using three groups of workers, we were able to create one group of full-time exposed workers, line operators, and one group of full-time non-exposed workers, non-exposed employees. The third group, non-line operators, encompassed those employees who were neither exposed full-time nor unexposed full-time. Consequently, we were able to analyze differences between obviously exposed and obviously non-exposed individuals, i.e., enhance the specificity of the analyses. However, attempts to retain specificity tend to result in groups with imprecise estimates of exposure (Werner and Attfield 2000). Therefore, an objection against the classification into the three exposure groups, as described in the methods section, might be that this could result in misclassification. For example, if a worker worked for 11 months as a non-exposed employee and one months as line operator, he or she would be classified as a non-line operator. However, more than one job title was reported in only 1 686 (10.2%) of the 16 570 health examinations carried out in the study. Of the 1 686 health examinations with more than one job title, 684 were classified as line operators or non-exposed employees, meaning that all the registered job titles were classified as either line operator or non-exposed. This leaves us with less than 6.0% (1002/16 570) to be a possible mix of line operator, non-line operator, and non-exposed. As our goal was to compare the obviously exposed group (line operators) with the obviously non-exposed group (non-exposed employees), we believe this possible misclassification to be of little importance.

Although the group of non-line operators appears heterogeneous, the exposure estimates for this group were between those of the non-exposed employees and those of line operators, indicating that our classification enabled us to sort out the highest exposed group (Paper IV).

10.1.3.2. Quantitative exposure classification – the JEM

One of the aims of the present study was to examine the relationship between current occupational exposure in the smelters and annual change in lung function among the employees. The reason for choosing current exposure, and not cumulative exposure, is the belief that as cigarette smoke is a mixture of particulates and gases it can be compared to a mixed inhalation exposure at a workplace (Becklake 1989). Tobacco smoking has been found to be associated with increased annual decline in FEV_1 in current smokers but not in former smokers (Fletcher and Peto 1977; Anthonisen et al. 1994). Consequently, the dust exposure concentration levels for every year the participants spent in the study were calculated and used in the analyses.

Even though the quantitative JEM is thought to be superior to the qualitative exposure classification, a JEM based on exposure measurements may have several limitations due to variation in measurements and misclassification (Stewart et al. 1991; Seixas and Checkoway 1995). Undoubtedly, intra person and between person variability of exposure were present in our study as in other industry-specific studies. Job tasks conducted by workers with identical job titles probably varied between the smelters, leading to a misclassification when the dust exposure concentration level for a given job title was assigned to employees in smelters without dust measurements for the actual job title (Goldberg et al. 1993; Seixas and Checkoway 1995; Benke et al. 2000). Further, the fact that women were assigned the same dust exposure level for a given job title as men may lead to a probable misclassification, as women have been found to be less exposed than men with identical job titles (Messing et al. 1994). Consequently, it may be assumed that the present study of the relationship between exposure and health outcome may suffer from misclassifications that may bias the results when the JEM is used in the statistical analyses. In epidemiologic studies, exposure misclassification is typically thought to be non-differential because exposure assessment is made independently of the health outcome (Blair et al. 2007). Hence, the misclassification would lead to a weakening of the association between dust exposure and health outcome, i.e., lung function (Goldberg et al. 1993).

The MP casette used for dust sampling in this study has been found to overestimate the thoracic fraction for particulates with aerodynamic diameters > 15 μm (Vincent J. 1995; Kenny et al. 1997). This might bias the results of the epidemiologic analyses but is nevertheless not thought to be of great importance as the majority of the particulates in the smelting industry have been found to have a diameter below this level (Kolderup 1977; Ellingsen et al. 2003; Friede 2006; Skogstad et al. 2006).

A direct link between the exposure group of the JEM (job title/department/smelter) and the job titles of the employees was achieved in 47% of cases in the SiMn/FeMn/FeCr production group but only in 25% of cases in the FeSi/Si-metal production group. Therefore, one might expect a greater misclassification of exposure in the FeSi/Si-metal production group than in the SiMn/FeMn/FeCr production group (Paper IV). The consequence of this might be an attenuation of the association between dust exposure and lung function in the FeSi/Si-metal production group compared to the SiMn/FeMn/FeCr group. This might explain, at least to some extend, the difference in association between exposure and decline in FEV_1/height^2 between the analyses using the qualitative exposure classification and the analyses using the JEM in the FeSi/Si-metal production group (Papers III and V).

A direct link between the job title of the employees and the dust exposure of the job title or department in the particular smelter was achieved for 87% of the registrations (Table 4). For the remaining cases, estimates of dust exposure were constructed using the dust concentration levels of the job title in the corresponding production group or in all the smelters. This method of using broader exposure groups when the exposure measurement data become scarce resembles the method used by Seixas et al. in a subcohort of the National Study of Coal Workers' Pneumoconiosis (Seixas et al. 1991). In that study, the authors used a procedure for estimating mean exposures by three-way occupation/mine/year-specific strata. Where data for a particular three-way stratum were lacking, mean values of the appropriate two-way or one-way strata were substituted (Seixas et al. 1991). This approach of using broader exposure groups as the exposure data become scarce is likely to produce misclassification as the job tasks for a given job title differ between the smelters (Kromhout et al. 1987; Stewart et al. 1996; Tielemans et al. 1998). It is, however, difficult to know if these misclassifications would lead to an over- or underestimation of dust exposure concentration levels.

In the furnace house, a difference in dust exposure concentration levels between the tappers and furnace operators was found using mixed model analyses (Paper IV). Unfortunately, we were not able to differentiate between these two job titles in 10 of the 15 smelters due to a lack of specificity in the work histories obtained from the questionnaires (eight out of 11 smelters in the FeSi/Si-metal production group and two out of four smelters in the SiMn/FeMn/FeCr production group). This lack of specificity very likely introduced a misclassification error as a new job title “furnace section worker” encompassing all the jobs of the furnace house was introduced. This misclassification is likely to weaken the association between dust exposure and health outcome in the epidemiological analyses as the highest exposed employees were assigned a dust exposure level below the true level and the lowest exposed employees were assigned a dust exposure level above the actual level.

10.1.3.3. Comparison between the exposure classifications

The qualitative exposure classification was used for cross-sectional and longitudinal analyses performed before the quantitative exposure classification was available (Papers I, II, and III). Therefore, it was of some interest to compare the qualitative exposure classification and the JEM.

Non-exposed employees were assigned 1% of the dust exposure concentration of the departments of the corresponding smelter as a whole (excluding the electrode and refractory departments), and employees regarded as partly exposed were assigned 10% of the dust exposure concentration levels of the smelter. Therefore, analyses comparing the exposure levels of the groups of line operators, non-line operators, and non-exposed employees were performed solely between line operators and non-line operators, with exclusion of the non-exposed employees and the non-line operators assigned a 10% dust exposure (Paper IV). In these analyses we found a significant difference in dust exposure between line operators and non-line operators of 1.4 mg/m^3 (95% CI: 1.3–1.6, p<0.0001).

10.1.4. Definition of airflow limitation

The practice of using the fixed ratio 0.70 as the lower limit of the FEV_1/FVC ratio has been shown to underestimate airflow obstruction in 20- to 49-year-old individuals and to overestimate it in the elderly (Hardie et al. 2002; Hnizdo et al. 2006). The analyses were therefore performed using FEV_1/FVC below the 5th percentile of the predicted value as the lower limit for FEV_1/FVC (LLN FEV_1/FVC) (Pellegrino et al. 2005; Hansen et al. 2007). Airflow limitation was defined as an FEV_1/FVC ratio below LLN FEV_1/FVC.

When using the definition of airflow limitation of FEV_1/FVC below LLN FEV_1/FVC instead of FEV_1/FVC below the fixed ratio of 0.70 and $FEV_1 < 80\%$ of predicted, the prevalence of airflow limitation increased from 144 (3.7%) to 294 (7.5%) in the study population.

10.2. Discussion of results

10.2.1. Respiratory symptoms

The prevalence of respiratory symptoms among the employees at inclusion to the study was found to be significantly associated with both current job function and previous occupational exposure (Paper I). The strongest relationship was found between respiratory symptoms and previous occupational exposure. This finding is in line with those findings of other studies (Bakke et al. 1991a; Trupin et al. 2003). The reason for the great impact of reported previous occupational exposure to dust, fumes, or gases on respiratory symptoms but not on the level of lung function at inclusion is unclear. However, it might be in accordance with the fact that chronic cough and sputum production may precede the development of airflow limitation by many years (Rabe et al. 2007). Another explanation might be that the relationship between respiratory symptoms and previous exposure to dust, fumes, or gases could be disturbed by recall bias (Rothman 2002). Employees with respiratory symptoms tend to recall any previous exposure better than individuals without respiratory symptoms.

10.2.2. Familial asthma, allergy, and doctor diagnosed asthma

At inclusion, the prevalence of allergy and doctor-diagnosed asthma was found to be highest in the non-exposed employee group. This agrees with the finding that employees with atopy are more likely than non-allergic subjects to work in unexposed sites (Meijer et al. 2001). This also indicates that some selection bias between the groups might exist. The multivariate analyses of the association between lung function and occupational exposure (qualitative exposure classification) at inclusion using ordinary least square regression revealed that employees reporting familial asthma or doctor-diagnosed asthma had a lower FVC and FEV_1 than those not reporting familial asthma or doctor-diagnosed asthma (Paper II). Regarding reported allergy no such association was found. In the longitudinal analyses using mixed model analyses with FEV_1/height^2 as dependent variable and with exposure expressed by the qualitative exposure classification, we found a strong negative association between doctor-diagnosed asthma and the level of FEV_1/height^2. Furthermore, we found that the product term between doctor-diagnosed asthma and time was not significant. This indicates that employees with doctor-diagnosed asthma do not have an accelerated annual decline in FEV_1/height^2 compared with employees without doctor-diagnosed asthma. In the longitudinal analyses using the quantitative JEM (FeSi/Si-metal and SiMn/FeMn/FeCr productions), no association was found between doctor-diagnosed asthma and FEV_1/height^2, although a negative association was found between familial asthma and FEV_1/height^2. In an earlier study in the aluminum industry, an accelerated annual decline of FEV_1 was found in workers reporting potroom asthma (Soyseth et al. 1994). The results of other longitudinal studies in general populations have been conflicting (Lange et al. 1998; Sherrill et al. 2003).

For the occupational physician, it is important to know whether patients with asthma should avoid working in the smelting industry. Therefore, the finding in the present study that employees reporting doctor-diagnosed asthma did not have a faster annual decline in FEV_1/height^2 than employees not reporting doctor-diagnosed asthma may be of interest. The present results do not justify the preclusion of asthmatic patients from work in the industry. However, occupational physicians should take individual considerations into account regarding subjects with asthma and these should be followed closely.

Regarding allergy, the longitudinal analyses using the quantitative JEM for exposure classification revealed neither an association between the product term of allergy and time nor between allergy and FEV_1/height^2. Consequently, it seems that subjects reporting allergy are not more susceptible to total dust exposure regarding lung function impairment than non-allergic subjects in this industry.

10.2.3. Body weight and lung function

Although a negative association between FEV_1/height^2 and body weight was found in the longitudinal analyses, no association between annual decline in FEV_1/height^2 and body weight was found (Papers III and V). This result contrasts those of other studies where weight gain was found to be associated with decline in lung function (Wang et al. 1997; Wise et al. 1998). The reason for this could be that not only high but also low weight was associated with a lower FEV_1, or it could be because of smoking cessation by the employees. Over the study period, the participants gained weight and the prevalence of current smokers decreased, while the prevalence of former smokers increased (Paper III). This finding agrees with those of other studies (O'Hara et al. 1998; Filozof et al. 2004). The reason why not only high body weight but also low body weight was related to lower FEV_1 and FVC is not clear. However, low weight has been found to be a predictor of the severity of COPD and might be part of the systemic effects of the disease (Agusti 2007).

10.2.4. Previous exposure

Previous exposure was defined as present when participants answered “yes” to the question “Have you previously been exposed on a regular basis to fumes, dust, or irritating vapors (gases) during your work?” The response to the question may be influenced by different definitions of “previously.” However, as this question, among others, has been evaluated in a separate study, and the kappa value was found to be 0.61, which is regarded as good, we do think that the question should be taken into account (Kongerud et al. 1989).

Interestingly, previous exposure was found to have great impact on respiratory symptoms at inclusion, but not on lung function (Papers I and II). Furthermore, employees reporting previous exposure to dust, fumes, or gases were found to have higher dust exposure than those not reporting such previous exposure (Paper IV). However, this association was significant only in the FeSi/Si-metal production group. In the longitudinal analyses of the association between dust exposure and lung function, previous exposure was found to be associated with current dust exposure and with FEV_1/height^2, though not significant in the SiMn/FeMn/FeCr production group (Paper V). The stratified analyses performed in the FeSi/Si-metal production group revealed that the annual decline in FEV_1/height^2 due to dust exposure and current smoking was significantly increased in employees reporting no previous exposure to dust, fumes, or gases compared with employees reporting previous exposure.

The findings that previous exposure showed no impact on lung function at inclusion and that the annual decline in FEV_1/height^2 was increased in those reporting no previous exposure (FeSi/Si-metal production) could be due to selection (Papers II and V). Employees less susceptible to air pollutants tolerate exposed workplaces better than susceptible subjects, and hence hold more exposed jobs (Kauffmann et al. 1982; Becklake and Lalloo 1990). Thus, subjects in the group reporting no previous exposure to dust, fumes, or gases, might be more susceptible to air pollutants than employees reporting previous exposure, as susceptible individuals already might have disappeared from the group of previously exposed workers. However, no association between "drop out" and previous exposure was found in a study of predictors of "drop out" in the same cohort (Soyseth et al. 2008). The findings in the present study therefore indicate that employees reporting previous exposure to dust, fumes, or gases are not more susceptible to current occupational exposure than employees without such previous exposure.

10.2.5. Airflow limitation

As the study population comprised healthy working individuals, we decided not to include the criterion of FEV_1 below 80% of predicted in the definition of airflow limitation, in accordance with the GOLD criterion for COPD (Rabe et al. 2007). We nevertheless in addition performed the analyses using FEV_1/FVC below LLN FEV_1/FVC and FEV_1 in percent of predicted below 80%, as "airflow limitation". The association between current exposure expressed by job category and airflow limitation using this definition were found to be unchanged when line and non-line operators were compared to non-exposed employees – line operators: OR=1.6 (95% CI: 0.71–3.7); and non-line operators: OR=1.5 (0.64–3.4); compared with line operators: OR=1.4 (0.85–2.4); and non-line operators: OR=1.5 (0.90-2.4), when airflow limitation was defined as FEV_1/FVC below LLN FEV_1/FVC.

The prevalence of airflow limitation in the present study is not directly comparable with the prevalence of airflow limitation in studies performed in general populations (Bakke et al. 1991b; Hnizdo et al. 2002). In the two studies cited, the fixed definition of airflow limitation with an FEV_1 less than 80% of predicted and $FEV_1/FVC<0.70$ were used. When this definition was used in the present analyses, the prevalence of airflow limitation was 3.7%, i.e., lower than in the two studies. This is not surprising as workers who develop respiratory impairment seem to be more likely to leave their jobs than those who remain healthy (Kauffmann et al. 1982; Soyseth et al. 1997; Soyseth et al. 2008). Workers have also been found to leave polluted jobs more often than unpolluted jobs (Bakke et al. 1992).

10.2.6. Lung function and exposure

At inclusion to the study we found lower lung function, expressed by FEV_1 and FVC, among line and non-line operators compared with non-exposed employees (Paper II). The finding not only of a lower FEV_1 but also of a lower FVC might indicate that an element of restriction of lung volumes might be present. Many of the employees in the Norwegian smelting industry have been exposed to quartz dust for years, and thus a possible restriction of lung volumes cannot be excluded (Bakke et al. 1991b; Hnizdo and Vallyathan 2003). However, the prevalence of classic mineral dust-induced silicosis has decreased and is not the main challenge of most developed countries today (Galton-Fenzi, B 1998; Hnizdo and Vallyathan 2003).

The longitudinal analyses were performed using both the qualitative exposure classification and the quantitative JEM. However, the analyses using the qualitative exposure classification included all four production groups, while those using the quantitative JEM included only the FeSi/Si-metal and SiMn/FeMn/FeCr production groups.

The finding that line operators in the FeSi/Si-metal producing smelters had a steeper annual decline in FEV_1/height^2 compared to non-exposed employees (not significant in the SiMn/FeMn/FeCr smelters) (Paper III), and the finding of a significantly increased decline in FEV_1/height^2 with increasing dust exposure in SiMn/FeMn/FeCr production but only in non smokers in the FeSi/Si-metal production (Paper V), appear to be contradictory. However, the use of the two different exposure classification systems, the qualitative exposure classification and the quantitative JEM, might explain the differing results, even though the average exposure of line operators, non-line operators, and non-exposed employees differed significantly (Paper IV). Misclassification in the quantitative JEM would tend to weaken the relationship between exposure and health outcome, i.e., lung function (Goldberg et al. 1993). As described earlier, misclassification of dust exposure concentration levels for the exposure groups is most likely greater in the FeSi/Si-metal production group than in the SiMn/FeMn/FeCr production group. This could be an explanation for the weaker association found between dust exposure and lung function impairment in the FeSi/Si-metal group than in the SiMn/FeMn/FeCr production group. However, we do not have an explanation for the weaker association between job category and lung function in the SiMn/FeMn/FeCr production group when the qualitative exposure classification was used.

In the longitudinal analyses we found an accelerated annual decline in FEV_1 with increasing dust exposure (Paper V). In the SiMn/FeMn/FeCr production group, the yearly decline in FEV_1 per mg dust exposure in a 1.80 m tall employee was 3.6 ml×year^{-1}. For non-smokers in the FeSi/Si-metal production group, the yearly decline in FEV_1 per mg dust exposure in an employee of equal height was 2.9 ml×year^{-1}. The median GM of the time-weighted dust exposure concentration levels of the employees was 2.3 mg/m^3 in the FeSi/Si-metal producing smelters and 1.6 mg/m^3 in the SiMn/FeMn/FeCr smelters. Thus, with the average exposure in the two production groups, the annual decline in FEV_1 due to dust exposure in a 1.80 m tall employee would be 6.7 ml/year in non-smokers in the FeSi/Si-metal production group and 5.8 ml/year in the SiMn/FeMn/FeCr production group. This is below the findings of a Norwegian study of tunnel construction workers (10.6 ml/year), English and South African coal miners (8-9 ml/year), and silicon carbide production workers (8.2 ml/year) (Marine et al. 1988; Osterman et al. 1989b; Cowie and

Mabena 1991; Ulvestad et al. 2001). However, it is only slightly below the current view that occupational exposure adds an extra decline in FEV_1 of 7 to 8 ml/year (Toren and Balmes 2007). By comparison, the annual effect of current smoking in the present study in an employee 1.80 m tall was 6.2 ml/year in the FeSi/Si-metal group and 5.8 ml/year in the SiMn/FeMn/FeCr group.

10.2.7. Current smoking

Smoking was associated with increased prevalence of respiratory symptoms, and the prevalence increased with increasing tobacco consumption (Paper I). This finding agrees with other reports (Langhammer et al. 2000).

The dose-response relationships found between tobacco consumption and lung function and between tobacco consumption and airflow limitation are in accordance with other studies and confirm that the adjustment for smoking in the present study is adequate (Osterman et al. 1989b; Langhammer et al. 2003; Johannessen et al. 2005).

The average loss of FEV_1 in current smokers was 40.2 ml/year, whereas non-smokers had a loss of 30.5 ml/year (Paper V). These figures are comparable to the findings of other studies (Soyseth et al. 1997; Post et al. 1998; Ulvestad et al. 2001; Bakke et al. 2004).

The longitudinal analyses revealed an excess yearly decline in FEV_1 of 6.5 and 5.2 ml/year in a 1.80 m tall employee due to current smoking (Papers III and V). These estimates are in line with estimates for current smoking found by others (Cowie and Mabena 1991; Humerfelt et al. 1993; Xu et al. 1994; Ulvestad et al. 2001).

The fact that smokers had higher dust exposure than non-smoking employees is thought to be caused by selection. Smoking employees may tolerate both workplace exposure and smoking better than non-smoking employees (Becklake and Lalloo 1990).

10.3. Validity of the results

The crucial points in studies of lung function and exposure are the precision of both lung function testing and exposure classification (Hnizdo et al. 2005). In the present study, the health examinations of the employees were performed by the local occupational health services at the smelters, which presents a challenge of comparability between tests performed at different centers by different technicians (Humerfelt et al. 1998b).

Consequently, the validity of the study results to a great extent depend on the quality of the lung function testing, the precision of the exposure assessments, and the comparability between the examinations performed at different centers.

Several precautions were taken to strengthen comparability between the different centers, i.e., the local occupational health services, and to quality assure the lung function testing. First, spirometry was performed in accordance with the European Community for Steel and Coal (ECSC) guidelines (Quanjer et al. 1993). Second, the spirometers used in the study met the specifications of the ATS and the ECSC (ATS 1991; Quanjer et al. 1993). Third, the technicians who conducted the spirometric procedures in the study underwent training both before and during the study. Fourth, the technicians were provided with a written protocol on lung function testing. Fifth, regular follow-up courses for evaluation were conducted during the study period.

The precision of the exposure classification has been addressed above. In conclusion, some misclassification is undoubtedly present, but as this misclassification is primarily non-differential, it would tend to weaken the association between exposure and health outcome (Goldberg et al. 1993). As such, the results of the present study are not thought to be overestimated.

11. CONCLUSIONS

The cross-sectional analyses at inclusion to the study showed that in Norwegian smelters the prevalence of respiratory symptoms appears to be positively related to both current job function and previous exposure. Further, impairment of lung function among the employees was significantly related to the job categories of line operator and non-line operator in the cross-sectional analyses.

Analyses of dust exposure concentration levels revealed that the dust exposure levels of the employees were higher in the FeSi/Si-metal production group than in the SiMn/FeMn/FeCr production group. Age, gender, smoking status, and previous exposure were significant determinants of dust exposure.

The longitudinal analyses revealed that line operators in the FeSi/Si-metal and SiC producing smelters had a steeper annual decline in FEV_1/height^2 than non-exposed employees. When using the quantitative JEM for the FeSi/Si-metal and SiMn/FeMn/FeCr production groups, we found that in all smelters combined δFEV_1 was negatively associated with increasing dust exposure. This association was also significant among workers in SiMn/FeMn/FeCr smelters, whereas it was only significant among non-smokers in the FeSi/Si-metal smelters.

No association was found between reported doctor-diagnosed asthma, familial asthma, allergy or previous exposure and increased annual decline in lung function.

12. CURRENT OCCUPATIONAL EXPOSURE AND COPD

The overall goal of the present longitudinal study, when it was initialized in 1996, was to investigate whether the current occupational exposure in Norwegian smelters constitutes an increased risk of developing COPD in employees exposed to occupational air pollutants.

To answer this question, the matter of causality should be addressed. Causality describes the relationship between cause and effect (Hill 1965; Rothman and Greenland 2005). In the present study, the ultimate goal was to study the relationship between current occupational exposure (cause) and COPD (effect). In addition to the fulfillment of several criteria, the pathogeneses of the disease in question and the mechanism of the influence of the exposure on development of the disease need to be known in order to establish the existence of causality (Hill 1965). So far this is not the case for COPD and occupational exposure, as it is not the case even for tobacco smoking and COPD (Rothman and Greenland 2005).

Therefore, to answer the above question we must examine the indicators. The hallmark of COPD is widely considered to be a long-term increased annual decline in lung function (Rabe et al. 2007). In our study, we found an association between current occupational exposure and increased annual decline in lung function among employees (Papers III and V). We also found an association between level of lung function and occupational exposure (Paper II). As many as 97.5% of employees with airflow limitation who performed a reversibility test still had airflow limitation after inhalation of a bronchodilator (Paper II). Therefore, COPD rather than asthma is thought to be the main challenge in this industry. Also the finding of an association between current occupational exposure and increased prevalence of respiratory symptoms strengthens the assumption that current occupational exposure is associated with an increased risk of COPD in Norwegian smelters (Paper I).

In consequence, we do think that there is reason to believe that current occupational exposure in the Norwegian smelting industry constitutes an increased risk for developing COPD among exposed employees.

13. FUTURE RESEARCH AND RECOMMENDATIONS

13.1. Future research

Although there is consensus that workplace exposure to dust, fumes, and gases causes an accelerated decline of lung function, the actual mechanism for this causality remain unknown. Future research of inflammatory markers including induced sputum or bronchial lavage may shed light on this area.

Other recommendations for future research:

- Further analyses of the data in the present database to reveal the optimal frequency of lung function testing of employees.
- Development of respiratory surveillance programs for employees in the smelting industry.
- Longitudinal analyses of the prevalence of respiratory symptoms and current occupational exposure.
- Further investigations of dust size and physical chemical composition of dust in the different production groups.

13.2. Prevention of impaired lung function in employees

Prevention may be divided into primary and secondary prevention: primary prevention is the reduction or elimination of exposures, and secondary prevention is health surveillance and early case detection.

13.2.1. Primary prevention

Below are a number of recommendations for reduction of exposure:

- Reduction of exposure to inhaled dust, fumes, and gases through engineering controls: enclosure of the smelting process, better abatement techniques and more efficient exhaust ventilation, and use of filters (dust, fumes, and gas) in vehicles and staging cars.
- Automation and remote control of jobs in areas with high dust exposure levels.
- Best benchmarking, best job practice regarding reduction of occupational exposure.
- Increased use of protective respiratory equipment and development of new and improved personal airway protective equipment specifically tailored to the smelting industry.
- Reduction of the prevalence of current smoking and reduction in the tobacco consumption of current smokers.

13.2.2. Secondary prevention

Personal industrial hygiene monitoring of the workforce. Surveillance of the work place atmosphere through exposure measurements following installation of improved abatement techniques and exhaust installation.

Surveillance of exposed employees through regular health examinations including lung function testing.

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15. APPENDICES

15.1. Questionnaire. Initial examination (in English)

RESPIRATORY QUESTIONNAIRE
INITIAL EXAMINATION
(*The survey questionnaire should also be completed at inclusion to the study)*

NAME:____ DATE:_________

Date of birth:________________________________

Yes: No: Don't know:

1. Have you ever suffered from allergic rhinitis?

2. Did you suffer from allergic eczema (atopic eczema) as a child?

3. Have any of your parents, grandparents, brothers, or sisters
ever had asthma or asthmatic bronchitis?

4. Before you started your present job, have you ever been diagnosed with
asthma or asthmatic bronchitis by a doctor? **Yes, in adulthood: Yes, in childhood: No: Don't know:**

5. Have you often had long-lasting colds or bronchitis? **Yes: No: Don't know:**

6. Do you smoke, or have you ever smoked more than 1 cigarette a day?
Yes, I smoke:
Yes, but I stopped smoking more than one year ago:
Yes, but I stopped smoking less than one year ago:
No, I have never smoked:

--- **if "Yes" to question 6** ---

7. How many years have you smoked/did you smoke?.......................

8. In the time you have been a smoker, approximately how many cigarettes have you smoked a day?
(one packet of tobacco is equivalent to 50 cigarettes)
1-10 cigarettes a day:
10-20 cigarettes a day:
More than 20 cigarettes a day:

---

9. Have you previously been exposed on a regular basis to fumes, dust,
or irritating vapours (gases) during your work? **Yes: No: Don't know:**

--- **if "Yes" to question 9** ---

10.	Asbestos	Years:……	Fibers (ceramic/mineral)	Years:……
	Quartz/sand blasting	Years:……	Welding/cutting	Years:…....
	Oil/Solvents	Years:……	Gas (Sulfur dioxide, fluor etc.)	Years:........

Diisocyanates, hardener, varnish production, plastic-boat building, spray-painting Years:……
Other:…………………………………………………………………………...........………………….................
………………………………………………………………………………………... Years:……

15.2. Questionnaire. Initial examination (in Norwegian)

AMS-skjema nr. 1

LUFTVEISPLAGER
FØRSTEGANGSUNDERSØKELSE
(Overvåkingsskjema skal også fylles ut ved førstegangsundersøkelse)

NAVN:____ **DATO:**________

Fødselsdato/personnr:_____________________________

		JA	NEI	VET IKKE
1.	Har du eller har du hatt høysnue?	□	□	□
2.	Har du som barn hatt allergisk eksem (barneeksem)?	□	□	□
3.	Har eller har noen av dine foreldre, besteforeldre eller søsken hatt astma eller astmabronkitt?	□	□	□

4. **Har du noen gang fått diagnosen astma eller astmabronkitt av en lege før du begynte i ditt nåværende arbeid?** Ja, som voksen □ Ja, som barn □ Nei □ Vet ikke □

5. **Har du ofte hatt langvarige forkjølelser eller bronkitt?** Ja □ Nei □ Vet ikke □

6. **Røyker du eller har du noen gang røykt mer enn en sigarett daglig?**

Ja, røyker □
Ja, men sluttet for mer enn 1 år siden □
Ja, men sluttet for mindre enn 1 år siden □
Nei, aldri røykt □

-------------------- **Hvis «JA» på spørsmål 6** --------------------

7. **Hvor mange år har du røykt?** ....

8. **Omtrent hvor stort har ditt forbruk vært i den tiden du har røykt (i gjennomsnitt)?**
(1 pakke tobakk er 50 sigaretter)

1 - 10 sigaretter daglig □
10 - 20 sigaretter daglig □
Mer enn 20 sigaretter daglig □

---

9. **Har du tidligere hatt arbeid der du vanligvis ble utsatt for røyk, støv eller irriterende damper (gasser)?** Ja □ Nei □ Vet ikke □

-------------------- **Hvis «JA» på spørsmål 9** --------------------

10.

Asbest	Antall år:........	Fiberstoff (keramiske/mineral)	Antall år:........
Steinstøv/sandblåsing	Antall år:........	Sveising/skjæring	Antall år:........
Olje/løsemiddel	Antall år:........	Gass (svoveldioksid, fluorgass etc.)	Antall år:........
Isocyanat, herdere, lakkproduksjon, plastbåtproduksjon, sprøytelakkering			Antall år:........

Annet...
.... **Antall år:**........

15.3. Respiratory questionnaire (in English)

RESPIRATORY QUESTIONNAIRE
FOLLOW-UP

NAME:____ DATE:_________

Date of birth:__________________________________

The answers refer to the past 12 months

Yes: **No:**

1. Have you felt chest tightness (breathlessness) at any time during the past 12 months?

2. Have you felt wheezing in your chest at any time during the past 12 months?

3. Have you felt chest tightness and wheezing at the same time?

If you have answered 'No' to questions 1 to 3, please proceed to question 9

---

4. Do you get such symptoms only when you have a cold? **Yes:** **No:**

5. After being away from your job for several days, your symptoms are:
   a) gone or better:
   b) unchanged or worse:

6. Have you felt chest tightness or wheezing in the 24 hours immediately after work? **Yes:** **No:**

7. If you have had such symptoms, they are present:
   a) Every day:
   b) At least once a week:
   c) Less than once a week:
   d) Less than once a month:

Complete question 8 only if you have been employed for less than two years

8. If you have any of the symptoms above, did they start within one month of employment? **Yes:** **No:**

---

9. Have you ever used any asthma medication (spray/aerosol or powder)? **Yes:** **No:**

10. Have you ever had a persistent cough (excluding short colds)?

11. Have you had a cough for as long as three months in the past 12 months?

12. Do you usually bring up phlegm from your chest when coughing?

13. Do you use any airway protection (mask)?
    a) Always:
    b) Only on highly exposed jobs:
    c) Seldom:
    d) Never:

14. Do you smoke, and if so how much?
    No:
    1-10 cigarettes a day:
    10-20 cigarettes a day:
    More than 20 cigarettes a day:
    (one packet of tobacco is equivalent to 50 cigarettes)

TO BE COMPLETED BY THE OCCUPATIONAL HEALTH SERVICE

SMELTER……………………………………. DEPARTMENT………………………………

JOB CODE 1:…………………………………NUMBER OF MONTHS…………………….

JOB CODE 2:…………………………………NUMBER OF MONTHS…………………….

JOB CODE 3:…………………………………NUMBER OF MONTHS…………………….

Height:…………………………………………Weight:……………………………………….

RESULTS OF SPIROMETRY

AFTER INHALATION AEROSOL
(reversibility test)

	Expected	**Measured**	**%**	**Measured**	**%**
FVC					
FEV1					
FEV%					

15.4. Respiratory questionnaire (in Norwegian)

Luftveisplager
Overvåkningsskjema

AMS-skjema nr.2 (selvutfyllende)

Navn: ☐

Fødselsdato/personnr.: ☐☐☐☐☐☐☐☐☐☐☐ **Dato:** ☐☐.☐☐.☐☐

Svarene gjelder plager siste 12 måneder

	JA	NEI
1. Har du de siste 12 måneder følt deg tett i brystet (tungpustet)?	☐	☐
2. Har du de siste 12 måneder merket piping (hvesing)i brystet?	☐	☐
3. Har du hatt tetthet samtidig med piping?	☐	☐

Dersom du har svart nei på spørsmål 1 til 3, så gå videre til spørsmål nr.9

	JA	NEI
4. Kommer slike plager bare når du er forkjølet?	☐	☐

5. Når du har vært borte fra arbeidet i flere dager, er da plagene
 - a) borte eller bedre ☐
 - b) uendret eller verre ☐

	JA	NEI
6. Har du hatt tetthet eller piping i brystet i løpet av 24 timer etter avsluttet skift/arbeidsdag?	☐	☐

7. Dersom du har hatt slike plager, har du merket det
 - a) hver dag ☐
 - b) minst en gang pr. uke ☐
 - c) sjeldnere enn 1 gang pr. uke ☐
 - d) sjeldnere enn 1 gang pr. måned ☐

Spørsmål 8 fylles bare ut av dem som har vært ansatt mindre enn 2 år

	JA	NEI
8. Dersom du har hatt plager, begynte plagene innen 1 måned etter ansettelse?	☐	☐
9. Har du brukt astmamedisiner (spray eller pulver)?	☐	☐
10. Har du hatt hoste? (Forkjølelse regnes ikke med)	☐	☐
11. Har du hatt hoste de fleste dagene i en periode av minst 3 måneder de siste 12 måneder?	☐	☐
12. Har du vanligvis oppspytt fra brystet når du hoster?	☐	☐

13. Bruker du åndedrettsvern?
 - a) hele tiden ☐
 - b) ved utsatte jobber ☐
 - c) sjelden ☐
 - d) aldri ☐

14. Røyker du og i tilfelle hvor mye?
 - a) nei ☐
 - b) 1-10 sigaretter pr. dag ☐
 - c) 10-20 sigaretter pr. dag ☐
 - d) mer enn 20 sigaretter pr. dag ☐

(1 pakke tobakk tilsvarer 50 sigaretter)

FYLLES UT AV HELSEAVDELINGEN

VERK:..AVDELING:..

JOBBKODE 1:..ANTALL MÅNEDER:..

JOBBKODE 2:..ANTALL MÅNEDER:..

JOBBKODE 3:..ANTALL MÅNEDER:..

Høyde:.. Vekt:...

SPIROMETRIRESULTATER

ETTER SPRAY
(Reversibilitetstest)

	Forventet	**Målt**	**%**	**Målt**	**%**
FVC					
FEV1					
FEV%					

	JA	NEI
OMPLASSERT PÅ GRUNN AV LUFTVEISPLAGER SISTE ÅR?	☐	☐

16. PAPER I TO V

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Quantitative and Qualitative Assessment of Exposure among Employees in Norwegian Smelters

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Objectives: To generate a job exposure matrix (JEM) for dust exposure in Norwegian smelters to be used in an epidemiologic study of respiratory diseases and to identify determinants of exposure.

Methods: The arithmetic mean and geometric mean (GM) of 2619 personal dust exposure measurements were applied in constructing the JEM, which was assigned to 2620 employees participating in a respiratory survey including yearly spirometry and a respiratory questionnaire. A qualitative exposure classification was constructed: (i) line operators were those employed full time in the production line, (ii) non-exposed employees were those who did not work in production and (iii) the remainder were classified as non-line operators.

Results: In the ferrosilicon alloy and silicon metal production group (FeSi/Si-metal), the median GM of dust exposure was 2.3 mg m^{-3} (0.04–5.6) (10–90% percentiles) compared with 1.6 mg m^{-3} (0.02–2.3) in the silicomanganese, ferromanganese and ferrochromium production group (SiMn/FeMn/FeCr). Multivariate analyses showed that dust exposure concentration levels decreased significantly with increasing age (FeSi/Si-metal), was significantly lower in females than in males and was significantly higher in current smokers than in never-smokers. Dust exposure concentration levels were also higher in employees reporting previous exposure to dust, fumes and gases than in employees without such previous exposure, though, significant only in the FeSi/Si-metal production group.

Conclusion: The dust exposure levels of the employees were higher in the FeSi/Si-metal production group than in the SiMn/FeMn/FeCr production group. Age, gender, smoking status and previous exposure were significant determinants of dust exposure and should be evaluated in future analyses of the relationship between health outcomes and dust exposure in this industry.

Keywords: job exposure matrix; longitudinal study; qualitative exposure classification; smelting industry; total dust exposure

INTRODUCTION

In epidemiological studies, various exposure indices have been used, including duration of exposure or employment, qualitative expert-based classifications of employees, employee work histories and job exposure matrices (JEM) based on measurements of specific exposure agents (Stewart *et al.*, 1991; Goldberg *et al.*, 1993; Blanc *et al.*, 2004). The advantages and limitations of different methods of exposure classification depend on the availability of data and the study design (Stewart *et al.*, 1991). In community studies, exposure assessed by an expert panel has been found to be preferable (Rybicki *et al.*, 1997; Benke *et al.*, 2001; de Vocht *et al.*, 2005). In industry-based studies, the ideal approach is quantitative measurements of exposure for each of the study subjects (Stewart *et al.*, 1996; Benke *et al.*, 2000; Checkoway *et al.*, 2004). This ideal goal is hardly ever accomplished, however, and an estimation of exposure has to be made (Goldberg *et al.*, 1993; Seixas and Checkoway, 1995).

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In constructing a JEM, the first step is to identify the exposure of interest (Seixas and Checkoway, 1995; Stewart *et al.*, 1996). In previous studies, dust has been found to be a predictor of lung function impairment (Kauffmann *et al.*, 1982; Becklake, 1989; Viegi and Di, 2002; Trupin *et al.*, 2003).

In 1996, the Norwegian smelting industry initiated a longitudinal respiratory study (Soyseth *et al.*, 2007). A quantitative JEM for all job groups in this industry was not available. The objectives of the present study were to generate a JEM for dust exposure for an epidemiologic respiratory study in Norwegian smelters, to compare this with a qualitative exposure classification and to identify determinants of exposure.

METHODS

Materials

Between 1996 and 2003, a total of 4234 industrial hygiene personal dust exposure measurements were carried out in 15 smelters, all members of the Norwegian Federation for Process Industry in 1996. During the period 1997–2001, all employees in these smelters were invited to participate in a respiratory survey with annual health examinations. At each examination, the 2620 participants, aged 20–55 years at inclusion, completed a standardized respiratory questionnaire including smoking habits and current job function.

The study was approved by the Regional Committee for Medical Research Ethics, Eastern Norway.

Production

The smelters and related workplaces serving the smelters were divided into two production groups: (i) ferrosilicon alloys (FeSi) and silicon metal (Si-metal) and (ii) other ferroalloys such as silicomanganese (SiMn), ferromanganese (FeMn) and ferrochromium (FeCr).

The production of metallic alloys in these smelters uses high temperature processes, with raw materials transported into the plant to be fed into a smelting furnace. The production requires carbon (such as coke, coal and in some cases charcoal and wood chips) in a solid form to reduce the minerals to molten metals, and a direct supply of electric power to achieve the necessary high process temperature. Electrical power is supplied through three submerged carbon electrodes. Three main types of electrodes are used: Søderberg electrodes, pre-baked electrodes or electrodes combining the characteristics of the other two types of electrodes, depending on the process. The Søderberg electrodes are self-baking carbon electrodes covered with an iron or steel casing, while pre-baked electrodes are baked before they are used in the smelting process.

When tapped from the furnace, the molten Si-metal or ferroalloys are poured out to cool in moulds and then finally crushed to specified sizes. In other production processes, some end products are sized by granulation. Dust is emitted into the working atmosphere during raw material handling, smelting, tapping (condensation of tapping fumes), crushing and handling of the end products. Job tasks by job title and department in the smelters are described in Table 1.

FeSi alloys and Si-metal production. The reduction materials are mixed with quartz and iron sources or other compounds depending on the end products. The raw materials are charged into the top of the cylindrical furnaces, which have a diameter of 5–13 m. The smelting temperature at the centre of the furnaces is typically between 1500 and 2000°C. The furnaces are partly open (Zulehner, 1993; Neuer and Rau,1993).

FeMn, SiMn and FeCr alloys production. Depending on the desired end product, the reduction materials are mixed with manganese ore or chromium ore, iron sources or other compounds such as quartz. In the sinter plants of FeMn and FeCr production, fine grain raw material ores are sintered into coarser materials. The temperature at the centre of the furnace reaches up to 1600°C (Wellbeloved *et al.*, 1990; Fichte, 1986). In contrast to FeSi and Si-metal production, where the furnaces are semi-closed or open-air furnaces, the furnaces in FeMn, SiMn and FeCr alloy production are closed.

In Norway, closed furnaces have wet scrubbers, scrubbing the furnace gas (with water) to get hold of the particulates. Semi-closed or open-air furnaces use ‘dry filter bag technology abatement’ to trap the condensed particles from the furnace gas. Thus, differences in the overall dust and gas exposure levels of the furnace house operators in the two production groups may exist.

Quantitative exposure classification and construction of JEM

More than 70% of the industrial hygiene dust exposure measurements in FeSi/Si-metal production and in the FeMn/SiMn alloy production were part of investigations performed by the National Institute of Occupational Health (NIOH) and were made available to our study. The measurements were performed randomly in accordance with the recommendations given by the Norwegian Labour Inspection Authority. The remaining dust exposure data originate from routine sampling programmes in the smelters and were analysed by three different laboratories serving the smelters.

Sampling and calculation of exposure estimates. Dust (so-called ‘total dust’) was collected at a sampling rate of 2 l min^{-1} on mixed cellulose filters (AAWP, Millipore Corporation, MA, USA) with an

Table 1. Job tasks by job title and department in Norwegian smelters

Department	Job title	Job tasks
Logistic	Transport operator	Unloading, loading, crane-, lorry- and truck driving.
	Raw material worker	Handling and mixing of the raw materials before charging the furnaces. Cleaning of conveyor belt.
	Logistic worker[a]	Unloading, loading, crane-, lorry- and truck driving. Handling and mixing of the raw materials before charging the furnaces. Cleaning of conveyor belt.
Furnace house	Furnace operator	Keeping process under control—operation from control room. Stoking car. Cleaning of area.
	Tapper	Tapping of ferroalloys and silicon metals from furnaces. Maintenance of tapping launders. Cleaning of area.
	Other job functions[b]	Granulating, refining, casting, pelletizing, producing of special alloys and cleaning of area.
	Furnace department worker	Job functions carried out in the furnace house not coded as one of the above-mentioned job titles (see Methods).
Filter	Filter department worker	Dust collection, granulating and filling of big bags. Cleaning of area.
Electrode	Electrode department worker	Electrode assembly, welding of electrode casing and filling of electrode paste.
Refractory	Ladle refractory worker[c]	Maintenance and repair of ladles and tapping launders.
Laboratory	Laboratory department worker	Sampling of metal product. Analytic work in the laboratory.
CSP	CSP department worker[d]	Crushing, screening and packing of the final metal and alloy products. Cleaning of area.
Maintenance	Mechanic[e]	Maintenance of machinery and production equipment.
	Electrician	Maintenance of electrical installations.
	Cleaner	Cleaning in the administration buildings and offices, control rooms and wardrobes in the production buildings.
	Other job functions	Wet filtering and handling of hazardous waste.
Sinter plants	Sintering worker	Sintering fine grain raw material ores into coarser materials (Mn, Cr, Fe).
Administration	Office work only	Never exposed in the production.
	Partly exposed	Primarily office work, but some periodically exposure in the production process.

CSP = crushing, screening and packing.
[a]CSP department workers were included in this job title in three smelters.
[b]In one smelter electrode, workers and refractory workers were included in the furnace house.
[c]Electrode workers were included in the refractory department in three smelters.
[d]Filter department workers were included in the CSP department in one smelter.
[e]Electrode workers were included as mechanics in three smelters. Refractory workers were included in one smelter.

0.8-μm pore size, fitted in 25 or 37 mm closed-faced three-part plastic cassettes (MP cassettes). The particle mass was measured using a microbalance (Sartorius AS, Goettingen, Germany) with a detection limit of 0.06 mg.

The MP cassette used in this study has been widely used for sampling so-called total dust. It seems that the sampling efficiency of particulates (aerosols) for this cassette is closer related to the thoracic fraction than to the inhalable fraction (CEN-convention: NS-EN 481, 1993). However, for particulates with aerodynamic diameters >15 μm, this cassette overestimates the thoracic fraction (Vincent, 1995; Kenny *et al.*, 1997).

The dust concentration measurements assembled were assessed as representative for the whole-study period as the measurements were performed randomly during the period and only minor changes in production and abatement technology were introduced. This assumption was supported by mixed-model analyses performed to assess if a time trend existed for the different job titles. A significant time trend was only found regarding two job titles in two smelters. When examined, it became clear that the time trend regarding these job titles was based on <10 measurements.

Of the 4234 personal dust exposure measurements performed, only samplings by MP cassette were used for the development of the JEM. Measurements made by MP cassettes were available in 13 smelters ($N_{\mathrm{MP\ cassette}}$ = 2680). Of the remaining 1554 personal measurements, 1497 were performed by Institute of Occupational Medicine (IOM) samplers (IOM, Edinburgh, UK) as part of a study comparing results obtained with MP cassettes and IOM samplers. As such, the measurements performed by IOM samplers were taken from the same individuals and at the same time as the measurements performed by MP cassettes.

Samples with a dust concentration level in excess of 50 mg m^{-3} were excluded as they were considered invalid due to sampling errors, as assessed by the industrial hygienist (S.M.H.), who has conducted exposure measurements projects in both the FeSi/Si-metal and the SiMn/FeMn/FeCr production groups and has extensive knowledge of the Norwegian smelting industry [number of excluded samples: n = 20, range 50–1905 mg m^{-3}, standard deviation (SD) 415 mg m^{-3}]. The 20 measurements with concentrations in excess of 50 mg m^{-3} were randomly distributed between the smelters and originated from eight of the 15 smelters encompassing 12 different job codes.

The average length of a shift during the study period was 480 min. Measurements with a sampling period of <240 min were excluded (n = 41, range 0.21–94 mg m^{-3}, SD 18 mg m^{-3}). Of the included measurements, 86% were recorded either as 'full shift' measurements or had a duration of ≥420 min. As such, the included industrial hygiene measurements were considered by the industrial hygienist (S.M.H.) to be the representative for the whole work shift and were not transformed into 8-h time-weighted averages.

If the measured personal dust exposure concentrations were less than the detection limit (3.5% of the measurements), the results were substituted by a concentration level equal half of the detection limit.

Finally, the data set used for construction of the JEM consisted of 2619 personal dust exposure measurements.

The arithmetic mean (AM) and geometric mean (GM) dust concentration level was assigned to the corresponding exposure group (smelter/department/job title) when five or more measurements were available. When less than five dust measurements were available for a given exposure group, the group was assigned the AM and GM dust exposure level of the respective job title in all smelters of the corresponding production group (FeSi/Si-metal or SiMn/FeMn/FeCr).

Employees in the administration department, who were regarded as non-exposed ('office work only' in Table 1), were assigned 1% of the AM and GM dust exposure concentration of all departments (exclusive electrode and refractory departments) of the corresponding smelter. Employees regarded as 'partly exposed', such as administrative personnel with part time supervision in the production, were assigned 10% of the AM and GM dust exposure concentration of the smelter. As only one personal dust exposure measurement existed for the job title 'maintenance cleaner', the dust exposure was assessed as half the exposure of the smelter (exclusive the electrode and refractory department).

In 10 out of 15 smelters, we were not able to differentiate between tappers, furnace operators and other job functions held by the operators in the furnace house section due to lacking specificity of the work histories. In these smelters, a new job title 'furnace section worker' was created and their dust exposure concentration estimated as the AM and GM of all the included dust measurements of the corresponding furnace house.

Exposure groups for the JEM. An exposure group was defined by a unique combination of smelter, department and job title. We used a classification system of job titles and departments developed by the smelting industry. The matrix included 15 smelters, with each smelter divided into departments (5–10 departments per smelter) encompassing 49 different job titles (6–16 job titles per smelter). As the job titles were unique for the different departments, this resulted in 222 unique groups of exposed workers (smelter/department/job title). In Table 1, 10 of the departments are shown, the remaining four departments were departments only associated with one smelter. In the same way, 19 of the 49 different job titles are shown. Even if not shown in Table 1, the specified job titles were used in the analyses.

Allocation of exposure for the employees. By each health examination, up to three job titles could be recorded for each of the 2620 employees participating in the respiratory survey. This resulted in 13 166 individual registrations during the 11 335 health examinations performed in the study period. The 222 unique combinations of smelter, department and job titles with a specific dust exposure concentration level were assigned to the employees as follows: where an employee had held more than one job in the 12 months prior to the health examination, the AM and GM of dust exposure for the employee were calculated weighted by the time spent in each of the jobs (with a maximum of three job titles). For time periods of no employment in the industry, i.e. employees on leave, an exposure of zero was assigned to the employees.

Qualitative exposure classification

The qualitative exposure classification of the employees was based on their job functions in the year before each health examination. This classification was used for cross-sectional and longitudinal analyses performed before the quantitative exposure classification was available (Johnsen *et al.*, 2007; Soyseth *et al.*, 2007; Johnsen *et al.*, 2008). The qualitative exposure classification has been thoroughly described in a former paper (Johnsen *et al.*, 2007). Briefly, the employees were classified into three exposure categories: (i) 'line operators' were those working full-time on the production line with handling and mixing of raw materials before charging the furnaces, all full-time jobs in the furnace house and crushing, screening and packing of end products; (ii) 'non-line operators' included employees loading and unloading raw materials and end products outside the plant, and employees working part time on the production line, such as foremen, maintenance and laboratory workers;

(iii) 'non-exposed employees' were primarily full-time office staff. Classification of each of the reported job titles into one of the three categories was made blinded in regard of all other information obtained from the respiratory questionnaire, such as health outcomes, smoking habits and previous exposure.

Data analyses

First multivariate mixed-model analyses were carried out to evaluate the differences in dust measurements between production group, departments and job titles and to explore if a time trend existed regarding the dust exposure levels. Second, the measured dust concentration levels were used to calculate the AM and GM of dust exposure in all 222 unique exposure groups. Based on these estimates, each employee was assigned a dust exposure concentration value as outlined above. As up to three job titles could be registered for each employee per year, the dust exposure concentration values were assigned time weighted to the employees. The medians of the GMs for each job across all of the workplaces in each production group were calculated. Third, univariate analyses were performed to investigate the association between dust exposure concentration levels and individual characteristics of the employees (data from the questionnaires used in the respiratory survey) (Fitzmaurice *et al.*, 2004). Fourth, the association between dust exposure concentration levels and individual characteristics was analysed using a multivariate linear mixed model. The strategy for model selection has been described elsewhere (Soyseth *et al.*, 2007). The Akaike Information Criterion was used for model selection (Sherrill and Viegi, 1996).

The following interaction terms were included in the initial models: line and non-line operator × production group, line and non-line operator × current smoking and line and non-line operator × former smoking.

In order to adjust for differences between the smelters, a dummy variable for each smelter was included in the model.

The analyses were performed using the Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL, USA; version 12.0.1) and SAS PROC MIXED (SAS Institute Inc., Cary, NC, USA; SAS version 9.1).

RESULTS

The distributions of the AM and GM of measured dust in the two production groups by department for the period 1996–2003 are shown in Table 2. The number of measurements was highest in the FeSi/Si-metal production group. This represented the largest production group, encompassing 11 smelters ($n_{\text{employees}}$ = 1697), compared with four smelters ($n_{\text{employees}}$ = 933) in the SiMn/FeMn/FeCr production group. The highest total dust concentration level was found for the sinter plant of the SiMn/FeMn/FeCr production group.

Table 3 shows the results of the multivariate mixed-model analyses, which were performed to evaluate the difference in measured dust exposure concentration levels for the production groups and for the different job titles. Job titles that were found in more than one smelter are shown in the table. The results showed no overall significant time trend for the measured dust exposure data. A significant difference between the two production groups, FeSi/Si-metal and SiMn/FeMn/FeCr, was found. Except for logistic workers, furnace operators, laboratory department workers, electricians and wet filtering workers all the job

Table 2. Dust exposure concentration levels (mg m^{-3}) based on the measurements in the two productions groups by department

Department	FeSi/Si-metal					SiMn/FeMn/FeCr				
			Percentile (GM)					Percentile (GM)		
	AM	GM	25%	75%	*n*	AM	GM	25%	75%	*n*
Logistic	2.1	0.91	0.30	2.5	208	3.9	1.9	0.89	4.0	92
Furnace house	4.2	3.0	1.8	5.2	786	2.4	1.5	0.80	2.9	173
Filter	3.6	2.2	0.95	4.5	169	1.3	0.53	0.20	1.0	26
Electrode	8.1	6.3	4.2	10.4	97	2.0	1.3	0.48	2.8	29
Refractory	7.4	5.1	2.8	9.1	196	3.0	2.0	0.91	3.8	64
Laboratory	3.0	0.71	0.30	1.4	50	0.82	0.77	0.62	0.96	12
CSP	3.7	2.4	1.3	4.5	216	2.8	1.9	1.1	2.9	94
Maintenance	3.1	2.0	1.1	3.8	208	3.3	1.7	0.86	3.5	81
Sintering plant						11.6	9.2	5.0	14.0	19
Other departments[a]	2.0	0.76	0.27	1.9	94	0.65	0.57	0.29	0.95	5
Total					2024					595

n = number of measurements. CSP = crushing, screening and packing.
[a]Administration departments as well as departments only associated with one smelter.

Table 3. The change in measured dust exposure (mg m^{-3}) during the study period, and the difference between different departments and job titles using mixed-model analyses. Transport operators are used as reference.

		Coeff.	n	95% CI		P-value
Time[a] (years)		−0.12	—	−0.37	0.11	0.30
FeSi/Si-metal compared with SiMn/FeMn/FeCr		2.0	2024	0.47	3.6	0.02
Department	Job title					
Logistics	Transport operator	—	108	—	—	—
	Raw material worker	3.5	147	2.2	4.7	<0.0001
	Logistic worker	0.57	45	−1.7	2.9	0.6
Furnace house	Furnace operator	1.3	259	−0.092	2.8	0.07
	Tapper	3.2	484	1.8	4.6	<0.0001
	Other job functions	2.9	202	1.5	4.4	<0.0001
Filter	Filter department worker	1.9	196	0.17	3.5	0.03
Electrode	Electrode department worker	3.9	126	2.2	5.7	<0.0001
Refractory	Ladle refractory worker	4.2	261	2.5	6.0	<0.0001
Laboratory	Laboratory department worker	1.5	61	−0.66	3.6	0.18
CSP	CSP department worker	2.5	310	0.99	4.1	0.001
Maintenance	Mechanic	2.1	222	0.34	3.8	0.02
	Electrician	−0.38	63	−2.4	1.6	0.71
	Wet filtering	−0.57	5	−4.8	3.7	0.79
Sinter plants	Sintering worker	11.7	19	8.8	14.7	<0.0001

Coeff. = coefficient of fixed effects. n = number of measurements. CI = confidence interval.
[a]Time (years) after 1996.

categories listed in Table 3 had higher dust exposure levels than transport operators.

An exact link between the job title of the employees (smelter/department/job title), collected during the respiratory survey, and the JEM exposure group was achieved for 4454 individual registrations (33.8% of all registrations). In 3881 individual registrations (29.5%), exposure was based on dust exposure concentration of the corresponding department. Due to inability to make a direct link, exposure in 1687 registrations (12.8%) was based on the dust exposure concentration of the respective job title or department in the production group and in 25 registrations (0.2%) the dust concentration of the respective job title or department in all the smelters (both FeSi/Si-metal and SiMn/FeMn/FeCr production) was used. The remaining 3127 registrations (23.8%) represented non-exposed and partly exposed employees as well as retired employees and employees on leave.

In Table 4, the estimated dust exposure of the job titles in 10 of the departments is presented for the two production groups. Overall dust exposure was found to be highest in the FeSi/Si-metal production group. The highest dust exposure concentration levels were found among electrode and refractory workers of the FeSi/Si-metal production group and among sinter plant workers of the SiMn/FeMn/FeCr production group. Because of the low number of workers in these jobs and as such the short total time spent here during the study, their contribution to the total exposure of the work force was modest. The number of smelters represented by the measurements is shown in Table 4.

Table 5 presents the univariate association between the dust exposure and the individual characteristics of the employees in the two production groups, using the time-weighted exposure estimates for the employees.

The time-weighted median GM of dust exposure for line operators, non-line operators and non-exposed employees in the study population was 2.6 mg m^{-3} (1.4–6.2) (10–90% percentiles), 1.1 mg m^{-3} (0.19–3.5) and 0.018 mg m^{-3} (0.013–0.054), respectively (data not shown).

In the multivariate analyses, the interaction terms between both line operators and non-line operators and the production groups were significant in the model where both production groups were included. Thus, the multivariate analyses were performed in separate models for each of the two production groups (Table 6).

Age was found to be negatively associated with dust exposure in all the models, indicating that the youngest employees had the highest exposure to dust (Table 6). This association was nevertheless not significant regarding the SiMn/FeMn/FeCr production group. Females were found to be less exposed to dust than males. Employees reporting previous exposure to dust, fumes or gases had higher dust exposure than employees not reporting such previous exposure.

Table 4. Dust exposure by job titles and departments in the two production groups

Department / Job title	FeSi/Si-metal							SiMn/FeMn/FeCr						
	AM	Median GM	Percentile (GM) 10%	Percentile (GM) 90%	n_1	n_2	Time (years)	AM	Median GM	Percentile (GM) 10%	Percentile (GM) 90%	n_1	n_2	Time (years)
Logistic	2.3	0.65	0.36	4.7	208	8	476	4.3	2.3	0.79	8.2	92	4	442
Transport operator	0.62	0.43	0.19	0.49	83	5	151	2.0	2.3	0.79	2.3	25	4	268
Raw material worker	6.1	2.9	1.8	10.8	80	7	61	6.7	2.8	2.3	8.2	67	4	174
Logistic worker	2.3	0.65	0.43	4.7	45	2	264	—	—	—	—	—	—	—
Furnace house	4.7	3.3	1.8	6.2	786	9	2635	2.4	1.6	0.92	2.0	173	4	1242
Furnacemen	2.5	2.1	1.2	2.1	234	9	249	1.0	0.92	0.29	0.92	25	2	163
Tappers	4.0	3.9	1.8	3.9	403	9	319	2.3	1.6	1.4	1.6	71	4	162
Other job functions	3.2	1.9	1.9	3.7	149	6	276	2.4	1.4	0.68	1.6	77	1	283
Furnace section workers	5.6	4.0	2.6	6.2	[a]	—	1791	3.1	2.0	1.8	2.0	[a]	—	634
Filter	3.8	2.2	1.7	2.2	169	6	185	2.3	0.95	0.43	0.95	26	2	30
Electrode	9.2	7.4	6.5	7.4	97	6	21	1.8	1.5	1.2	1.5	29	4	25
Refractory	7.4	5.3	2.7	8.7	196	7	285	3.0	2.0	1.9	2.7	64	3	167
Laboratory	2.1	0.41	0.27	12.6	50	4	153	0.83	0.77	0.77	0.88	12	2	147
CSP	4.2	3.3	2.1	3.3	216	5	313	2.7	2.0	0.66	2.5	94	4	167
Maintenance	3.2	2.5	0.98	3.5	208	7	1325	2.4	1.6	0.55	2.2	81	4	898
Mechanics	3.9	2.8	2.1	3.5	153	7	826	3.1	1.7	1.6	2.2	67	4	584
Electricians	1.6	1.1	0.96	1.3	55	3	331	1.0	0.82	0.55	0.82	8	3	202
Cleaning	2.3	0.90	0.70	3.4	[a]	—	132	1.8	1.1	0.85	1.1	1	1	68
Other job functions	3.4	1.6	1.6	3.5	[a]	—	36	0.35	0.26	0.26	0.26	5	1	44
Sintering plant	—	—	—	—	—	—	—	11.6	9.2	9.2	9.9	19	2	92
Administration	0.20	0.067	0.016	0.24	[a]	—	1479	0.26	0.17	0.013	0.57	[a]	—	973
Office work only	0.044	0.020	0.014	0.067	[a]	—	897	0.036	0.017	0.013	0.022	[a]	—	535
Partly exposed	0.42	0.22	0.15	0.55	[a]	—	582	0.48	0.20	0.20	0.57	5	1	438
Other departments[b]	1.6	0.63	0.51	0.63	94	2	129	—	—	—	—	—	—	—
Time-weighted means	3.3	2.3	0.037	5.6	2024	9	7105	2.2	1.6	0.022	2.3	595	4	4183

n_1 = number of dust exposure measurements. n_2 = number of smelters represented by the measurements. Time = time in department or job function during the study. CSP = crushing, screening and packing.

[a]As there were no dust measurements for these job titles from the respiratory survey, a dust concentration level was assessed as described in the Methods.

[b]Departments associated with only one smelter and not included elsewhere.

This association was significant only in the FeSi/Si-metal production group. The multivariate analyses also showed that the apparent decline in dust exposure concentration levels of the employees during the study (time in study) was significant for SiMn/FeMn/FeCr production only. In the SiMn/FeMn/FeCr production group, former and current smokers were found to have higher dust exposure than those who had never smoked.

The mixed-model analyses showed that the dust exposure was higher in non-line operators and line operators compared with non-exposed employees in the SiMn/FeMn/FeCr production group. As the dust exposure of non-exposed employees was computed as a preset percentage of the measured values, it is not meaningful to test these differences. The variables non-exposed employee, non-line operator and line operator were nevertheless included in the multivariate analyses because of confounding. To test for the difference between non-line operator and line operator, we performed the multivariate analyses excluding non-exposed employees and non-line operators with dust exposure estimated as 10% of the dust exposure of the smelter. These analyses showed that line operators had significantly higher dust exposure levels than non-line operators in both the FeSi/Si-metal and the SiMn/FeMn/FeCr production groups (results not shown).

In the FeSi/Si-metal production group, the interaction terms between both non-line operators and line operators and current smoking were found to be positive and significant. Thus, for this production group, the multivariate analyses were performed separately for current smokers and never-smokers. For currently smoking line operators, the GM of dust exposure concentration was 3.5 mg m^{-3} above the GM of dust exposure concentration for non-exposed employees, whereas the GM of dust exposure concentration of line operators who had never smoked was 3.2 mg m^{-3} above that of non-exposed employees. For non-line operators, the results for

Table 5. Distribution of dust exposure among employees during the study

	FeSi/Si-metal				SiMn/FeMn/FeCr			
		Median	Percentile (GM)			Median	Percentile (GM)	
	AM	GM	10%	90%	AM	GM	10%	90%
Operators								
Non-exposed	0.071	0.020	0.014	0.067	0.058	0.017	0.013	0.022
Non-line	2.5	1.1	0.16	3.9	1.9	0.88	0.22	2.3
Line	4.8	3.2	1.8	6.2	3.3	1.9	0.95	2.8
Previous exposure[a]	3.5	2.5	0.16	5.6	2.4	1.6	0.22	2.3
Gender								
Male	3.5	2.5	0.15	5.6	2.4	1.6	0.082	2.3
Female	1.7	0.41	0.016	3.4	1.1	0.22	0.013	2.0
Age at inclusion								
20–34 years	3.6	2.6	0.029	6.2	2.3	1.6	0.22	2.3
35–44 years	3.3	2.5	0.18	5.6	2.3	1.6	0.022	2.3
45–54 years	2.9	1.9	0.016	5.6	2.1	1.1	0.017	2.3
Test number[b]								
1	3.4	2.5	0.029	6.1	2.3	1.6	0.022	2.3
2	3.3	2.2	0.029	5.6	2.3	1.6	0.022	2.3
3	3.2	2.2	0.029	5.6	2.3	1.6	0.022	2.3
4	3.3	2.3	0.055	5.6	2.2	1.5	0.022	2.3
5	3.3	2.3	0.029	5.6	2.1	1.4	0.022	2.3
6	2.7	2.0	0.021	4.0	2.0	1.0	0.022	2.3
Smoking status								
Never[c]	3.3	2.3	0.021	5.6	1.8	0.82	0.017	2.2
Former[d]	3.0	2.1	0.021	5.6	2.3	1.5	0.022	2.3
Current[e]	3.4	2.3	0.076	5.6	2.5	1.6	0.22	2.3

AM = arithmetic mean of dust concentration levels (mg/m^{-3}). Median GM = median of geometric means of dust concentration levels (mg/m^{-3}). Time-weighted mean AM and median GM of the JEM.
[a]Previous exposure, on a regular basis, to fumes, dust or irritating vapours (gases) during work.
[b]Test number was the examination number in the employee respiratory survey.
[c]Never-smokers were lifelong non-smokers.
[d]Former smokers were smokers who had stopped smoking more than a year prior to the examination.
[e]Current smokers were active smokers or smokers who had stopped smoking less than a year prior to the examination.

Table 6. Results from the mixed-model analyses using the time-weighted GM of the dust exposure concentration levels for the employees as dependent variable ($mg\ m^{-3}$)

Covariates	FeSi, Si-metal		SiMn, FeMn, FeCr	
	Coeff. (SEM)	*P*-value	Coeff. (SEM)	*P*-value
Intercept	0.39 (0.16)	0.01	0.77 (0.22)	0.0004
Time independent				
Age at inclusion + 10 (years)	−0.13 (0.034)	<0.0001	−0.048 (0.047)	0.3
Female versus male	−0.36 (0.100)	0.0003	−0.45 (0.13)	0.0005
Non-line operator	*	—	0.74 (0.069)	<0.0001
Line operator	*	—	1.3 (0.083)	<0.0001
Previous exposure	0.20 (0.078)	0.009	0.14 (0.089)	0.1
Time dependent				
Time in study (years)	4.7×10^{-3} (0.0076)	0.5	−0.041 (0.013)	0.001
Former smoker	*	—	0.25 (0.074)	0.0007
Current smoker	*	—	0.18 (0.063)	0.004

Coeff. = coefficients of fixed effects. SEM = standard error of the mean. Time in study = years after inclusion. * = The interaction terms between current smoking and line operator and current smoking and non-line operator were positive and significant in the FeSi/Si-metal production group. For further details, see Results.

current smokers and never smokers were 1.7 and 0.71 mg m^{-3}, respectively.

DISCUSSION

Personal dust exposure concentration levels were generally higher in the FeSi/Si-metal production group than in the SiMn/FeMn/FeCr production group. Gender, age, current smoking, job categories and previous exposure were found to be important individual characteristics of the dust exposure concentration levels of the employees in these industries.

Methodological considerations

Classification of exposure in epidemiologic studies can be made using different methods (Stewart *et al.*, 1991; Checkoway *et al.*, 2004). In our study, a qualitative exposure classification and a JEM based on personal dust exposure measurements were constructed.

A JEM based on exposure measurements may have several limitations due to variation in measurements and misclassification (Seixas and Checkoway, 1995). First, the samples may not have been randomly collected, and as such the exposure assessment may be biased (Goldberg *et al.*, 1993; Stewart *et al.*, 1996). Furthermore, within each exposure group a considerable random variation may exist between different workers and from one day to another (Seixas and Checkoway, 1995). Moreover, job tasks carried out by workers with identical job titles may vary not only between smelters but also between individuals at the same smelter and of different gender, or job tasks may be performed with different frequencies or under different conditions (Goldberg *et al.*, 1993; Messing *et al.*, 1994; Seixas and Checkoway, 1995; Benke *et al.*, 2000). Thus, within each job category, there may be wide variation in the level of dust exposure, which may introduce systematic as well as random errors of the estimates.

In the present study, >70% of the dust exposure measurements were part of investigations performed by NIOH and were randomly collected. The remaining samples were part of the routine sampling programmes in the smelters and at least some of these samples might have been collected for compliance. Undoubtedly, an inter-person and between-person variability were present in our study as in other industry-specific studies. The job tasks carried out by workers with identical job titles varied between the smelters, leading to misclassification when the mean GM dust exposure for a given job title in one of the production groups was assigned to employees holding this job in smelters without dust measurements for the actual job title. Females were assigned the same dust exposure levels for a given job title as men, leading to a probably misclassification as females have been found to be less exposed than men within identical job titles (Messing *et al.*, 1994). As such, also the present study suffers from misclassification which may alter the results when the JEM is used in analyses of the association between exposure and health effects. In epidemiological studies, exposure misclassification is typically thought to be non-differential because exposure assessment is made independent of the health outcome (Blair *et al.*, 2007). As such, the present misclassification would lead to a weakening of the association between occupational dust exposure and health outcome in the epidemiological analyses (Goldberg *et al.*, 1993). As most of the exposure assessment in the FeSi/Si-metal production group was based on measurements from a smaller proportion of the smelters in the production group, than was the case in the SiMn/FeMn/FeCr production group, one could expect misclassification to be greatest in the former group.

The JEM was constructed for the period 1996 to 2003. No time trends of the dust exposure levels were found during this period. This was in accordance with the fact that only minor changes in production and workplace dust abatement technologies were introduced during the period. As such, the decline in the dust exposure levels of the employees in the SiMn/FeMn/FeCr production group during the study period could be explained by a decrease in the number of highest exposed workplaces in favour of less exposed workplaces.

An exact link between the job title of the employees from the respiratory survey and the exposure group of the JEM (job title or department in a given smelter) was achieved for >80% of the registrations. In the remaining cases, estimates of dust exposure were constructed using the AM and GM of the dust concentration levels in the corresponding production group. This method of using broader exposure groups when the exposure measurement data become scarce resembles the method used by Seixas *et al.* (1991) in their estimation of exposure for the national study of coal workers pneumonconiosis in US. Even when the above-mentioned estimates in the present study were based on recommendations of a skilled industrial hygienist (S.M.H.), this approach is likely to produce misclassification as the job tasks assigned to the job titles could differ somewhat between the various smelters (Kromhout *et al.*, 1987; Stewart *et al.*, 1996; Tielemans *et al.*, 1998). It is, however, difficult to know if these approximations would lead to overestimation or underestimation of dust exposure concentration levels. As the great majority of the samples were collected randomly, this misclassification should most likely be regarded as non-differential.

In the furnace house, a significant difference in dust exposure concentration levels between tappers and furnace operators was found. Unfortunately, we were not able to separate these two job functions of the employees in 10 of the 15 smelters. In these smelters, a new job title, 'furnace section worker', was constructed. Thus, in smelters where the job classification of the employees did not differentiate between tappers and furnace operators, the tappers were underestimated regarding exposure, whereas the furnace operators were overestimated. This misclassification is likely to weaken the association between health outcome and dust exposure in the epidemiological analyses.

In several of the departments, the 25th and the 75th percentile of the measured dust exposure concentration levels were approximately half and twice the median, respectively. There is therefore a 50% probability that the true dust exposure level was less than half or more than twice the estimated value, and we must expect that a considerable proportion of the workers were misclassified regarding dust exposure. Most likely, this misclassification was non-differential, leading to an underestimation of the relative risk (Goldberg *et al.*, 1993).

Dust exposure levels

Total dust exposure in the Norwegian smelting industry has been described to some extent in former studies (Langard, 1980; Kjuus *et al.*, 1986; Hobbesland *et al.*, 1997). Historically dust concentration >5 mg m^{-3} and upto 30 mg m^{-3} was not uncommon (Langard, 1980; Kjuus *et al.*, 1986). In a study from 1997, Hobbesland *et al.* describe that furnace workers in FeSi and Si-metal production had a total dust exposure of 3.4 mg m^{-3} (95% confidence interval: 1.1, 13.8) in the period 1986–1990 (Hobbesland *et al.*, 1997). The latter finding is comparable to our findings in the present study, indicating that only small changes in workplace exposure were observed from 1990 to 1996.

Individual characteristics of exposure

Some determinants of exposure need further comments. First, women were found to have lower dust exposure than men, and the oldest workers were found to have lower dust exposure than younger workers. As the dust exposure concentration level for a given exposure group (job title, department, smelter) was constant during the study period, the differences found in relation to gender and age during the study may originate from women holding less exposed jobs than men and the oldest employees holding less exposed jobs than the younger. Second, smokers were more exposed to dust than those who had never smoked. This finding is in accordance with the findings of others (Bakke *et al.*, 1990). Third, previous exposure status was a determinant of current exposure in the FeSi/Si-metal production group, i.e. it appeared that subjects with previous exposure to dust, fumes and gases continued to have higher exposure than their colleagues. Information about previous exposure to dust, fumes and gases before current job were obtained from the questionnaire used at the first time examination of the employees and as such made differential reporting likely. As the kappa value of this question in a separate study was 0.61, which is regarded as good, we do believe that the question of previous exposure should be taken into account (Kongerud *et al.*, 1989).

The reason for the positive relationship between both smoking and previous exposure and current occupational exposure is not known. It might be explained by differences in susceptibility to air pollutants and tobacco smoke: employees less susceptible to air pollutants or tobacco smoke tolerate exposed occupations better than susceptible subjects and hence continue in such jobs (Becklake and Lalloo, 1990). Though, others have found that the impact of smoking as a confounder in occupational studies is of minor importance (Blair *et al.*, 2007). The finding that women worked in less exposed jobs than men might also be explained by a higher susceptibility to air pollutants of females (Becklake and Kauffmann, 1999).

CONCLUSION

The dust exposure concentration levels of the employees were generally higher in the FeSi/Si-metal production group than in the SiMn/FeMn/FeCr production group. Gender, age, current smoking, job category and previous exposure were found to be significantly related to the dust exposure concentration levels of the employees and should therefore be evaluated in future analyses in this industry.

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